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CAPITAL AND OPERATING COST ESTIMATING SYSTEM HANDBOOK

MINING, RETORTING AND UPGRADING OF OIL SHALE IN COLORADO, UTAH AND WYOMING

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

by

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CAPITAL AND OPERATING COST ESTIMATING SYSTEM FOR MINING, RETORTING AND UPGRADING OF OIL SHALE IN COLORADO, UTAH AND WYOMING

This handbook was prepared by STRAAM Engineers, Inc., (formerly A. A. Mathews, Inc.) Mining Division, Arcadia, California, under United States Department of the Interior, Bureau of Mines Contract Number J0265049 for the Bureau of Land Management. The principal authors were Project Manager George K. Clement, Jr., P.E., Project Mining Engineer Robert L. Miller, P.E. and Project Investigator James P. apRoberts. The contract was administered under the technical direction of Mr. Pat Geehan, Bureau of Land Management Mineral Economist and Mrs. Darlene Wilson, Bureau of Mines Contract Administrator.

The views and conclusions contained in this document are those of STRAAM Engineers, Inc. and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Land Management or of the U. S. Government.

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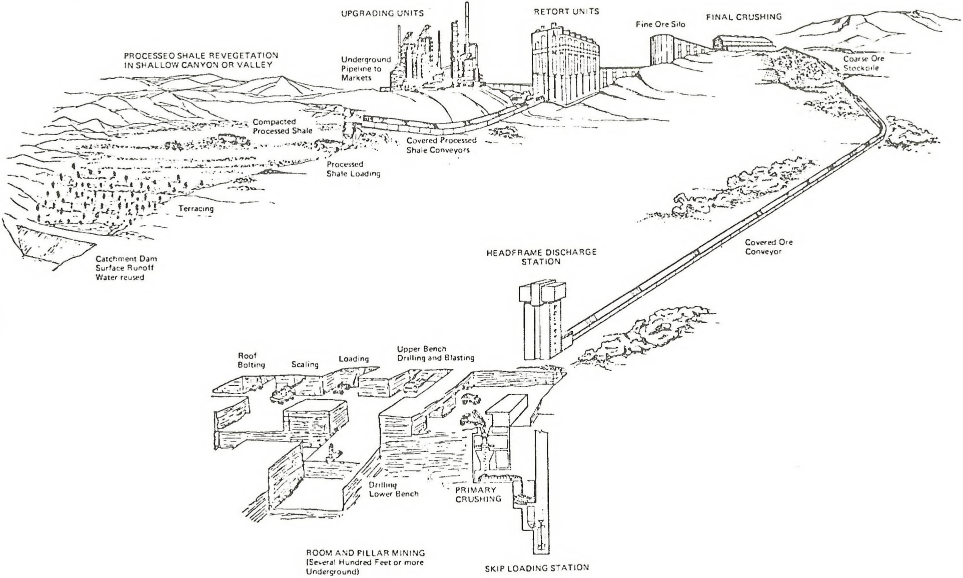
UPGRADING UNITS
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Underground Pipeline to Markets
Coarse Ore Stockpile
Compacted Processed Shale
Covered Processed Shale Conveyors
Processed Shale Loading
Terracing
Catchment Dam Surface Runoff Water reused
HEADFRAME DISCHARGE STATION
Covered Ore Conveyor
Roof Bolting
Scaling
Loading
Upper Bench Drilling and Blasting
Drilling Lower Bench
PRIMARY CRUSHING
ROOM AND PILLAR MINING (Several Hundred Feet or more Underground)
SKIP LOADING STATION

ARTIST'S RENDITION OF A SHALE OIL COMPLEX

1. FOREWORD

1.1. NEED FOR THE SYSTEM

The Bureau of Land Management (B.L.M.) of the United States Department of the Interior, as the manager of mineral resources on public domain lands, has need for a means of evaluating lands underlain by oil shale deposits and marketable by-products. This handbook was developed to assist the B.L.M. in the valuation of oil shale deposits which may be considered for leasing, exchange or patent.

While oil shale deposits extend over many areas of the United States the area of particular interest is the Green River formation in Colorado, Utah and Wyoming. The handbook has been developed based on studies and data concerned with oil shale in this particular area.

The cost of production of shale oil from the deposits of Colorado, Wyoming, and Utah have not been established for a commercial operation. Many studies have been made, pilot and semi-works plants have been operated, calculations and prognostications abound in the literature; but a functioning oil shale mine with processing plant and a marketable product has not been achieved. It is necessary to simulate the capital and operating cost based on the oil shale literature, gross estimates provided by entities active in oil shale development, experience in similar industries and engineering judgement.

Mining, retorting, mineral recoveries, upgrading, transportation and ancillary systems do not exist for the quantities of materials envisioned for a commercial oil shale project. The systems were simulated to the degree necessary to provide the cost basis and were not developed in detail. A large amount of engineering and testing remains to be done to develop flow sheets and size equipment that would provide the most efficient combination of elements. The costs obtainable from the use of this handbook will provide a means of determining an approximation of the costs of the individual units as constituted in the simulation and described in the handbook. In this manner, it will be possible to develop the costs of a total oil shale operation from exploration through mining, retorting and upgrading. Mining schemes considered in this handbook were limited to one system underground and one surface system. Different mining parameters will dictate different mining schemes and different equipment mixes. The underground mining system was chosen because it has been successfully operated in the oil shale deposit. The surface mining system was selected as the one most likely to be applicable to the initial project.

The treatment of the shale oil product from the retorts, both surface and in situ, depend on many factors including; quantity of shale oil, quality of shale oil and value of available by-products. Typical refinery processes are included for obtaining the available by-products from shale oil and a suggested slate of processes for various size operations is provided. The point in the upgrading process at which the shale oil becomes a marketable product will depend upon the individual project. No retort included in this manual produces a product that can be pumped at ambient temperatures. The constituents of the oil shale do not match the crude oil being produced in the region, indicating that a special refinery or refinery run will be required to process the shale oil.

The associated minerals, Nahcolite and Dawsonite, are treated in this handbook. It is recognized that other processes exist for the recovery of these minerals but it was considered logical to use the ones with the best available data. Neither of the processes described have been used on a commercial scale.

The costs and state-of-the-art used in this handbook are based on July, 1976. The authors have used data which was publicly available at that time and recognize that other methods and data have since been developed.

1.2. USE OF THE HANDBOOK

This handbook has been developed for a user with some skill in estimating. A knowledge of oil shale mining and processing is also necessary to effectively utilize the data presented herein.

The mining schemes, retorts models, modified in situ and ancillary minerals recovery processes utilized in the preparation of this handbook are only representations of major industry proposals. The state of development of the industry, the limited publication of cost details and the lack of availability of process details required that a significant amount of conceptual estimating and design simulation be employed in order to complete a logical flow through the various activities. As with any estimating system, the user must be guided by his own judgement in situations where there are significant deviations from the items described and costed in the handbook.

1.3. ACKNOWLEDGEMENTS

Data acquired for the preparation of this handbook came from many sources and in many forms. The Detailed Development Plans submitted to the Area Oil Shale Supervisor (AOSS), Department of the Interior for the federal lease tracts C-a, C-b, and U-a, and U-b were used extensively. The Environmental Impact Statements for the Colony project provided insight into the oil shale industry. Many publications were reviewed and data extracted, notably the proceedings of the nine oil shale symposia published by the Colorado School of Mines, and the Bureau of Mines publications on oil shale mining authored by Fenix and Scisson, Cameron Engineers, and the Sun Oil Company. Many personal interviews with engineers and scientists were conducted to obtain firsthand information and attitudes of individuals active in the oil shale development.

The following corporations and agencies were particularly helpful in providing literature describing their activities in oil shale, and contributed the time of their personnel for discussions with STRAAM Engineers, Inc., (formerly A. A. Mathews, Inc.).

Area Oil Shale Supervisor's Office, Grand Junction, Colorado

Colorado School of Mines Research Institute, Golden, Colorado

Energy Research and Development Agency, Laramie, Wyoming

Energy Research and Development Agency, Morgantown, West Va.

Paraho Demonstration Project, Grand Junction, Colorado

Rio Blanco Oil Shale Project, Denver, Colorado

Superior Oil Company, Houston, Texas

TOSCO Corporation, Los Angeles, California

Union Oil Company, Brea, California

United States Bureau of Mines, Denver, Colorado

United States Geological Survey, Denver, Colorado

2. GENERAL INFORMATION

2.1. PROCEDURES FOR ESTIMATING AND USE OF FACTORS

The estimating handbook is set up to use curves for obtaining costs directly from knowledge of the daily capacity of the element of the estimate. Where this was not possible, guidelines in narrative form are provided in the text. The estimating system is designed to cover retort production rates of from 1,500 cubic meters to 24,000 cubic meters of syncrude per day. The handbook assumes the land for the oil shale project has been acquired and that the quantity and quality are generally determined. Property and inventory taxes, permits, socio-economic developments and insurance are costs excluded from the curves. Environmental studies and confirmation drilling are the initial elements covered in the handbook. Mining, retorting, upgrading, transportation, and spent shale disposal are covered to provide a complete oil shale operation.

The user of the handbook should be knowledgeable of the requirements of an oil shale operation to the extent that he can select the elements of the operation. The curves are based on oil shale containing 0.146 cubic meters of shale oil per metric ton. Formulas are provided to convert this grade of oil shale to any other desired grade. In order to determine the quantities to be used as input into the various curves, it is necessary for the user to select the method of retorting to be used and the quantity of shale oil to be produced. With this value known and with the use of the equations and/or factors given in this handbook, the input quantities to the various curves can be determined. In the areas of mining and retorting, it is necessary to set the daily production rate. The cost is then taken directly from the curve. In the instance of upgrading, the production rates are expressed in cubic meters or metric tons.

Each element contains sufficient descriptive narrative to enable the user to determine the cost and apply it to his estimate. In this manner an estimate containing the selected options can be assembled.

The labor costs are based on the costs in effect in the Denver and Grand Junction, Colorado area during 1976. The labor costs include a payroll burden of 35% to cover vacation, sick leave, holidays, insurance (medical, dental, disability, life and accident), payroll taxes, and retirement funds. Exceptions to this general cost do occur and are noted in the specific instances in the text.

Electric power is generally treated as a supplies cost rather than part of equipment operation. The electrical power used throughout the handbook is constant at 25 mils ($0.025) per kW-h. Any variance from this rate should be applied as a factor to the electric power cost as identified in the text.

Cost of treated or purchased water used throughout this handbook is constant at $0.10 per cubic meter. Any variance from this rate should be applied as a supplies factor using the percentage of the supplies cost as noted in the text.

A sample problem is provided in Section 14., Sample Problem, of the handbook. This problem should be followed until the user becomes familiar with the contents and use of the handbook.

2.2. DATA REQUIREMENTS FOR AN ESTIMATE

The estimating system is designed for treating the oil shale of the Green River formation located in Colorado, Utah and Wyoming. Use in other areas is dependent upon the similarity to the basic region and is a matter of judgement.

The basic data required for an estimate is listed below. Assumptions may be necessary to define all the parameters, but this is consistent with estimating in general.

Areal extent of the property

Grade of the oil shale

Specific gravity of the oil shale

Percentage Nahcolite content

Percentage Dawsonite content

General mine geometry

Daily production rate in cubic meters of shale oil

Upgrading components

Spent shale disposal geometry

Product transportation mode.

Ground water regimen

In order to determine the quantity of oil shale to be mined, it is first necessary to determine the retorting method and the shale oil content of the ore. With this data and the equations given in Section 4., Underground Mining, a determination of the quantity of ore to be mined may be made.

The estimating system provided by this handbook does not recognize a time element. The expenditures are all considered to be made instantaneously. Provisions for the cost of capital to finance expenditures occurring over the years required for development of a property from exploration to design production is the responsibility of the user. The costs given will be in July 1976 dollars and should be extrapolated to the time frame in which the expenditure actually occurs. Significant errors in estimated costs could occur in improperly applying the expenditures required to equip and operate an oil shale project.

2.3. COST INDEXES

The following cost indexes may be used to adjust cost data in this handbook and are based on, "Employment and Earnings" and "Wholesale Prices and Price Indexes" both published by the U.S. Department of Labor, Bureau of Labor Statistics (B.L.S.) with base year 1967 = 100, except Transportation base year 1969 = 100. Also used are "Engineering News Record Construction Labor and Construction Materials Index" (E.N.R.) with base year 1913 = 100 for Skilled Labor (BC) and base year 1967 = 100 for Materials; Oil and Gas Journal Nelson Operating Cost Index for Refineries" (O.G.J.) with base year 1956 = 100; and "Construction Index for Refineries" with base year 1946 = 100 are used for items associated with Retorting and Upgrading.

No.	Item	Cost Index	Source	Value July '76
1.	Mine & Plant Labor*	Mining Labor Table C-1	B.L.S.	$6.39/hr
2.	Construction Labor	Skilled Labor (BC)	E.N.R.	2171.2
3.	Retorting & Upgrading**	Refineries (Operation)	O.G.J.	209.0
4.	Equipment & Repair Parts	Equipment Table 4 Code 11-2	B.L.S.	199.8
5.	Bits & Related Steel	Iron & Steel Table 4 Code 10-1	B.L.S.	219.7
6.	Fuel	Petroleum Table 4 Code 05-7	B.L.S.	276.2
7.	Retorting & Upgrading***	Refineries (Constr.)	O.G.J.	615.7
8.	Tires	Tire Table 4 Code 07-12	B.L.S.	157.1
9.	Construction Materials	Materials (Denver)	E.N.R.	203.0
10.	Industrial Materials****	Industrial Commodities Table 2	B.L.S.	182.6
11.	Transportation	Chem or Allied Products Table 14 Code 28	B.L.S.	183.6

* Rate does not include burden.

** Includes Labor, Equipment Operation & Supplies.

*** New facilities construction.

**** Use for miscellaneous items. Industrial Commodities index reporting in Table 2 discontinued by B.L.S. in March, 1978. Values given in Table 6 may be used thereafter, but the user may be required to determine the yearly average from the monthly reports until the summary is issued in the latter part of the year following subject year.

The individual cost indexes are included as a convenience to the user and not as a complete basis for escalation. The user must depend on his own judgement when selecting the cost index to be used with this handbook. It is not essential to the use of this handbook that any of the above indexes be used and other indexes that are available treating costs in a more general manner may be more appropriate to the users needs. It is necessary to bear in mind that the costs in the handbook are based on July 1976, therefore the adjustment should be made from this base irregardless of the index or technique used to place the cost in the desired time frame.

At the time of this study, no commercial oil shale industry exists. Therefore no experience is available that would prove the viability of the indexes listed or any other index that might be applied. The user must rely on his knowledge of estimating as to the proper index to apply and also the place in the estimate that it sould be applied.

Shown below are the annual averages for the eleven cost indexes.

Year	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1974	$5.21	1836.0	159.7	152.3	178.6	223.4	522.7	133.4	167.0	153.8	147.9
1975	$5.90	1982.1	189.3	185.2	200.9	257.5	575.5	148.5	186.3	171.5	168.4
1976	$6.42	2087.2	209.3	198.9	215.9	276.6	615.7	161.5	205.5	182.3	183.8
1977	$6.88	2265.6	228.2	213.7	230.3	308.1	653.0	169.9	237.7	195.1	197.1

2.4. CONVERSION TABLES

The handbook utilizes the metric system exclusively. Where the terms "tons", "long tons", "cubic yards" and "inches" are used, they designate manufacturers' sizes in the United States System.

Where the term "barrel" is used, it designates capacity of 42 gallons under the United States System and is used to provide the user with a base line for determination of the refinery units used in the United States.

It is recognized that the United States System predominates in both the mining and petroleum industries which are combined in the oil shale industry. The following tables are provided to permit ease of conversion from one system to the other.

2.4 CONVERSION TABLE Sheet 1 of 2

WEIGHT EQUIVALENTS

KILOGRAM	POUND	METRIC TON	SHORT TON
1	2.205	10^{-3}	1.102×10^{-3}
4.536×10^{-1}	1	4.536×10^{-4}	5×10^{-4}
10^{3}	2.205×10^{3}	1	1.102
9.072×10^{2}	2×10^{3}	9.072×10^{-1}	1

LINEAR EQUIVALENTS

CENTIMETER	METER	KILOMETER	INCH	FOOT	MILE
1	10^{-2}	10^{-5}	3.937×10^{-1}	3.281×10^{-2}	6.214×10^{-6}
10^{2}	1	10^{-3}	3.937×10^{1}	3.281	6.214×10^{-4}
10^{5}	10^{3}	1	3.937×10^{4}	3.281×10^{3}	6.214×10^{-1}
2.540	2.54×10^{-2}	2.54×10^{-5}	1	8.333×10^{-2}	1.578×10^{-5}
3.048×10^{1}	3.048×10^{-1}	3.048×10^{-4}	1.2×10^{1}	1	1.894×10^{-4}
1.609×10^{5}	1.609×10^{3}	1.609	6.336×10^{4}	5.280×10^{3}	1

SQUARE EQUIVALENTS

CENTIMETER	METER	KILOMETER	INCH	FOOT	MILE
1	10^{-4}	10^{-10}	1.550×10^{-1}	1.076×10^{-3}	3.861×10^{-11}
10^{4}	1	10^{-6}	1.550×10^{3}	1.076×10^{1}	3.861×10^{-7}
10^{10}	10^{6}	1	1.550×10^{9}	1.076×10^{7}	3.861×10^{-1}
6.452	6.452×10^{-4}	6.452×10^{-10}	1	6.944×10^{-3}	2.490×10^{-10}
9.290×10^{2}	9.290×10^{-2}	9.290×10^{-8}	1.440×10^{2}	1	3.587×10^{-8}
2.590×10^{10}	2.590×10^{6}	2.590	4.014×10^{9}	2.788×10^{7}	1

2.4 CONVERSION TABLE Sheet 2 of 2

LAND EQUIVALENTS

SQ. METER	SQ. KILOMETER	HECTARE	SQ. FOOT	SQ. MILE	ACRE
1	10^{-6}	10^{-4}	1.076×10^{1}	3.861×10^{-7}	2.471×10^{-4}
10^{6}	1	1.0×10^{2}	1.076×10^{7}	3.861×10^{-1}	2.471×10^{2}
10^{4}	1.0×10^{-2}	1	1.076×10^{5}	3.861×10^{-3}	2.471
9.290×10^{-2}	9.290×10^{-8}	9.290×10^{-6}	1	3.587×10^{-8}	2.296×10^{-5}
2.590×10^{6}	2.590	2.590×10^{2}	2.788×10^{7}	1	6.40×10^{2}
4.047×10^{3}	4.047×10^{-3}	4.047×10^{-1}	4.356×10^{4}	1.563×10^{-3}	1

VOLUME EQUIVALENTS

LITER	CUBIC METER	GALLON	CUBIC FOOT	BARREL	CUBIC YARD
1	10^{-3}	2.642×10^{-1}	3.531×10^{-2}	6.290×10^{-3}	1.308×10^{-3}
10^{3}	1	2.642×10^{2}	3.531×10^{1}	6.290	1.308
3.785	3.785×10^{-3}	1	1.337×10^{-1}	2.381×10^{-2}	4.951×10^{-3}
2.832×10^{1}	2.832×10^{-2}	7.481	1	1.781×10^{-1}	3.704×10^{-2}
1.590×10^{2}	1.590×10^{-1}	4.200×10^{1}	5.614	1	2.079×10^{-1}
7.646×10^{2}	7.646×10^{-1}	2.020×10^{2}	2.7×10^{1}	4.809	1

MISCELLANEOUS CONVERSION FACTORS

KILOJOULE/CM^{3}	BTU/FT^{3}
1	2.684×10^{4}
3.725×10^{-5}	1

CUBIC METER/ METRIC TON	GAL/SHORT TON
1	2.397×10^{2}
4.172×10^{-3}	1

CUBIC METER	ACRE FOOT
1	8.106×10^{-4}
1.234×10^{3}	1

3. PREDEVELOPMENT

Predevelopment costs considered are those involved in environmental studies, exploration drilling, and well logging and assaying for shale oil content. It is recognized that significant costs other than those stated may accrue during predevelopment work. Land acquisition and retention expenses are a major category not treated in this study. The three considered are common to any oil shale venture, whereas other predevelopment costs are functions of the specific property in question.

3.1. ENVIRONMENTAL STUDIES

Environmental studies costs are not well established at this time. Wide variations may be encountered from project to project. Factors that need to be assessed in estimating the cost of environmental studies are:

1. Nature of the data available. Is it necessary to develop the information or will an analysis of existing data be sufficient?

2. Attitude of external interests toward the project. Is there existing or potential opposition to the project that will require extreme detail in the study to satisfy?

3. Likelihood of a legal challenge. Will there be costs due to legal actions or additional studies?

4. The status of the project. Is the project designed with all sources of environmental impact determined or will the environmental studies iterate as the project progresses?

The above factors depend on many variables within the industry and the nation.

The cost of the environmental studies for one of the Federal lease tracts is quoted at $6,000,000 over a three year period. This results in a cost of $2,900 per hectare. Similar work on other projects have given results of $270 per hectare. The latter value is believed to be the more representative cost at this time.

3.2. EXPLORATION

Exploration costs are restricted to those incurred in drilling, logging and assaying for the purpose of proving the oil shale reserve and providing information for mine and process systems design. The regional geologic effort, including preliminary core holes, is considered to have been accomplished, and no cost is assigned to this function.

3.2.1. CORE DRILLING AND LOGGING

Oil shale is comparatively consistent in areal extent in the study area allowing wide spacing for the drill holes. Depending on the local geology, hole spacing varies from one hole per 50 to one hole per 200 hectares. Due to the ease of access and sparse vegetation, site preparation and access road costs are minor and are absorbed in the drilling charge. Logging costs vary depending on the logs required. A suite of logs that will provide rock and formation characteristics was selected and priced. Costs for drilling and logging in the study area are summarized in Table 3.2.1.

Engineering analysis of the cores and logs to determine the physical characteristics of the rock may be desirable. This information could include a Rock Quality Designation (RQD) and be utilized in the selection of the mining method. The costs per meter of hole depends on the detail required, the nature of the rock and the information available from previous work in the formation. The following program is assumed to provide the necessary information.

Labor (geologist) @ $3.00/meter
    (examines cores from 2 holes/day or 12 meters)
Laboratory testing @ $5.00/meter
    (one test @ $10.00 per 2 meters of core)

Rock mechanics services may then be estimated at $8.00 per meter of drilled hole.

TABLE 3.2.1

DESCRIPTION	COST PER UNIT	REMARKS
Drilling and Coring		
6" (15.24 cm) diameter hole	$60/m	Includes access and site preparation
Logging		
General		
Service Charge	$300/hole	
Instrument Insurance	$30/logging service	
Data Processing		
Volume and Weight	$1.67/m	Recording interval
Rock Properties	$220/1st 300 m	
	$0.17/m over 300 m	Recording interval
Services		
3D Velocity	$0.62/m	Core hole depth
	$0.49/m	Recording interval
Density	$0.56/m	Core hole depth
	$0.43/m	Recording interval
Acoustic	$0.62/m	Core hole depth
	$0.49/m	Recording interval
Neutron	$0.62/m	Core hole depth
	$0.49/m	Recording interval

Using the above unit prices, a cost per hole may be arrived at based on a 1000 meter deep hole, 900 meter recording interval and 4 services.

$$\begin{aligned}\text{Cost per hole} &= (300)+(4)(30)+(220)+(.17)(900-300)\\ &\quad +(1000)(60+.62+.56+.62+.62)\\ &\quad +(900)(1.67+.49+.43+.49+.49) = \$66,375\end{aligned}$$

Therefore, the cost of core drilling and logging other depths can be approximated by the following formula:

$$\text{Cost} = \$66\text{x}10^3(D/1000)(N)$$

Where:
D = Average depth of hole
N = Number of holes
If number of holes are not known, use:
N = Area/100

3.2.2. ASSAYING

The cost of assaying will depend on the number of assays required for a specific hole. Assaying costs are based upon the use of the Fischer assay. The cost per assay is $5.50 and sample collection and preparation is $0.50 yielding a total cost of $6.00. Sample interval will depend on the judgement of the sample program manager. An interval of 1.5 meters of core hole per sample is selected as nominal. The cost of assaying the 1,000 meter hole in Table 3.2.1. then becomes (900/1.5)(6.00) = $3,600.

Costs for assaying may then be computed by the following formula:

$$\text{Cost} = \$3{,}600(D/1000)(N)$$

Where:

D = Average depth of hole
N = Number of holes
If number of holes are not known, use:
N = Area/100

4. UNDERGROUND MINING

The estimating system for underground mining is based on a room and pillar mine plan. This system of mining has been used in the extraction of over one million tons of oil shale at the Colony mine and at the Anvil Points mine. Other mining systems are possible, but it is logical to utilize one that has proved effective to reduce the unknown quantities.

The candidate mining horizons selected for the estimate basis are the Mahogany zone or similar kerogen rich zones. In the area of study the mining zones vary in thickness from 12 meters to 25 meters. A top heading followed by a bench would serve to excavate this interval and is the system used.

The mining costs are based on metric tons of material produced and must be adjusted by shale oil content to obtain the desired quantity of oil shale production. The costs are based on oil shale containing 0.146 cubic meters of shale oil per metric ton with a specific gravity of 2.07. The following formula is used to determine the desired production.

$$A = D/X$$

Where:

A = mine production in metric tons per day
D = retort syncrude production in cubic meters per day
X = shale oil content in cubic meters per ton

Example:

If the oil shale contains 0.125 cubic meters of shale oil per metric ton and the desired production rate is 4,770 cubic meters of shale oil per day, the daily mine production is determined by:

$$A = 4{,}770/0.125 = 36{,}160 \text{ metric tons per day}$$

In the instance of a multi-mineral oil shale operation, it is necessary to adjust the mine production to compensate for the shale oil lost in the Nahcolite process. The feedstock shale assay must be determined to obtain the proper tonnage to apply to the retort cost curve. The required data may be determined by the following formulas.

$$A = D/\{X[1-.2(Y)]\}$$
$$B = 0.8(A)(Y)$$
$$C = A(1-Y)$$
$$E = C-W(D)$$
$$F = 0.256(V)[A-0.25(B)]$$
$$G = E-F$$
$$Z = \{X[1-.2(Y)]/(1-Y)\}$$

Where:

A = mine production in metric tons per day
B = Nahcolite production in metric tons per day
C = retort feed in metric tons per day

D = retort syncrude production in cubic meters per day
E = retorted spent shale in metric tons per day
F = Alumina production in metric tons per day
G = Alumina recovery waste material in metric tons per day
V = percent of Dawsonite assay/100
W = specific gravity of syncrude
X = shale oil content of mine production in cubic meters per ton
Y = percent of Nahcolite assay/100
Z = shale oil content of retort feed in cubic meters per ton

Example:

If the oil shale mined contains 0.130 cubic meters of shale oil (specific gravity of 0.95) per metric ton, 18% Nahcolite, 11% Dawsonite and the desired production rate is 4,770 cubic meters per day of shale oil, the daily mine production and other items are determined by:

$Y = 18/100 = .18$
$A = 4{,}770/\{0.130[1-.2(.18)]\} = 38{,}062$ metric tons per day
Use 38,000 metric tons per day
$B = 0.8(38{,}000)(.18) = 5{,}472$ metric tons per day
$C = 38{,}000(1-.18) = 31{,}160$ metric tons per day
$Z = \{0.130[1-.2(.18)]/(1-.18)\} =$
0.153 cubic meters per ton
$E = 31{,}160-0.95(4{,}770) = 26{,}628$ metric tons per day
$V = 11/100 = .11$
$F = 0.256(.11)[38{,}000-0.25(5{,}472)] =$
1,032 metric tons per day
$G = 26{,}628-1{,}032 = 25{,}596$ metric tons per day

Laboratory testing * indicates that lower grade oil shale has higher specific gravity and, thus, occupies less volume than the higher grade material. This refinement is not considered in this handbook, but may be made by the user should it become desirable.

The underground costs are based on mining depths of 300, 500 and 1,000 meters with access by shaft. Inclines or adits are used in the case of an outcrop. Adjustments for items that are affected by depths are provided by factors or by using a weight-distance dimension. The pillar sizes will vary with depth, but the effect on the cost of excavation will be insignificant, therefore, no adjustment is necessary for this case.

The oil shale mines considered are very large in comparison with other underground mines. The costs for the equipment used in this estimating system are based on existing equipment sized to provide a compatible combination for a sectionalized mining operation. The face cycle consists of drilling, loading and blasting, loading of muck, scaling and rock bolting. The equipment includes jumbo mounted rotary drills, giraffe truck loading and blasting units, front end loaders, off road truck haulers, back hoe configured scalers, scissors trucks, wagon drills, and road graders.

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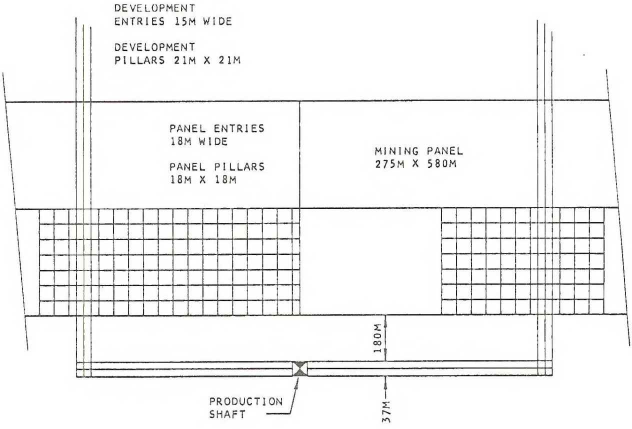
* "Rock Mechanics Research on Oil Shale Mining: SME/AIME Transactions v. 252, No. 2, June, 1972" by J. B. Sellars, G. R. Haworth and P. G. Zambas.


DEVELOPMENT
ENTRIES 15M WIDE
DEVELOPMENT
PILLARS 21M X 21M
PANEL ENTRIES
18M WIDE
PANEL PILLARS
18M X 18M
MINING PANEL
275M X 580M
180M
PRODUCTION
SHAFT
37M

DRAWING 4.1.1.1. MINING CONCEPT - ROOM AND PILLAR

4.1. CAPITAL COSTS

Capital costs are based on the planned production in metric tons per day. Normally, the cost of a capital item may be determined by calculating the required production rate in metric tons per day and then referring to the appropriate curve, reading the estimated cost directly. It is also necessary in some instances to select the depth to the main mining level and the haul distance.

4.1.1. PREPRODUCTION DEVELOPMENT

Preproduction development costs are those costs incurred in opening the mine to the extent necessary to provide a reliable supply of oil shale to the processing unit at the design production rate. The cost items are mine development and access. The mine development consists of driving main entries, panel entries, and opening up sufficient panel faces to provide a continuous supply of oil shale at the design production rate. The mine development is independent of the depth below surface and the means of access, whether by shaft, incline or adit.

4.1.1.1. MINE DEVELOPMENT

The mine plan used as the basis for developing the cost is illustrated in Drawing 4. One or more three-entry headings are driven to obtain access to the production area. The headings are driven on 37 meter centers with a width of 15 meters. Cross-cuts are also placed on 37 meter centers with 15 meter widths. When the development entry has passed the panel limits, eight rooms are turned off at 90 degrees on either side as panel entries. The panel entries are the same height as the development entries and on the same centers, but are 3 meters wider. The cross cuts are also increased by 3 meters with a resulting decrease in panel pillar size compared to development entries. A bench is started below the panel floor to include the total mining interval. The bench follows the panel plan and is restricted to a minimum of 120 meters from an active panel face.

The curve is for the mine development cost only and does not include haulage by hoisting or conveying from the development area to the surface. If a shaft or incline is used, the operating cost of these facilities must be added to the mine development costs. These costs are determined by establishing the operating cost on a daily basis using the mining production rate and hauling distance from Figure 4.2.4.1., Hoisting or 4.2.4.2., Conveyor Hauling. The daily operating cost is then multiplied by the number of days required for mine development. The days required for mine development is obtained by multiplying the selected daily production rate by 1.25×10^{-3}. No adjustment for access is required if the mine is entered by adit.

The amount of oil shale produced during the mine development phase may be calculated by the following formula:

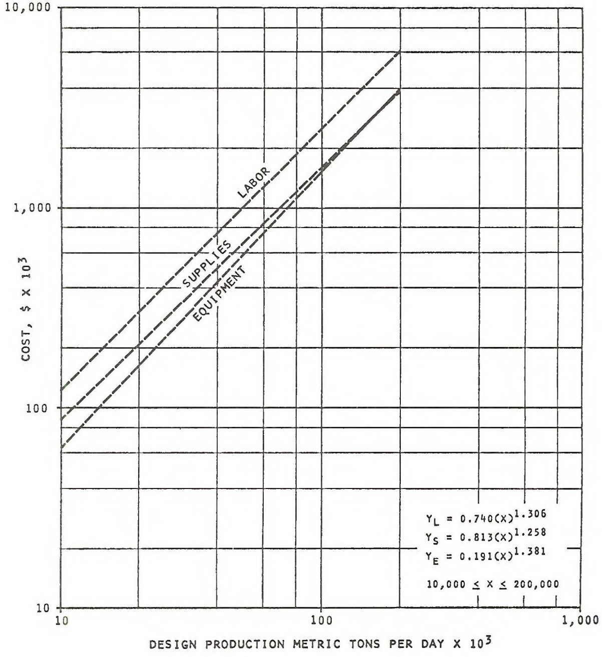
$$T = 0.341(\text{MTPD})^{1.416}$$

Where:
T = tons of mine development oil shale
MTPD = metric ton per day production

The labor curve contains the labor costs incurred during the mine development phase for face excavation, mine services, and administrative salaries.

Supplies are those materials expended during mine development including 40% blasting agents, 42% rock bolts, 8% administrative expenses and 10% ventilation stoppings and piping.

Equipment operation includes 36% fuel and lubrication, 20% repair parts and 44% tires for the mobile equipment utilized in mine development.



SCALE - LOGARITHMIC

4.1.1.1. MINE DEVELOPMENT
CAPITAL COST

4.1.1.2. ACCESS SHAFTS

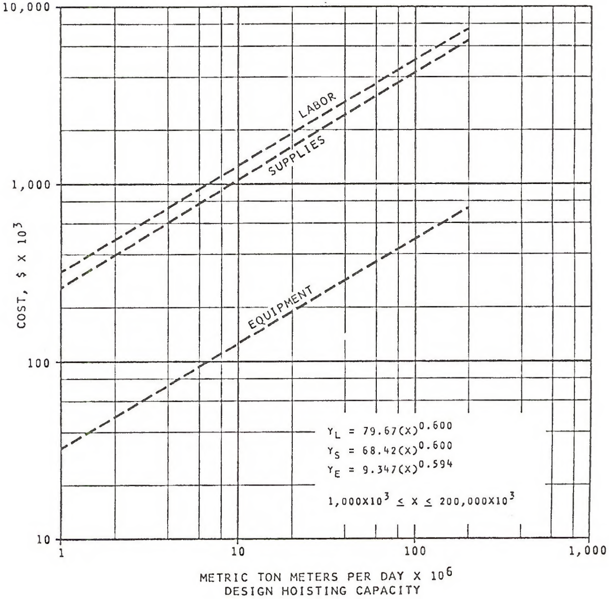
The access shafts are for men and materials and for production hoisting of oil shale. Ventilation shafts are considered separately. Hoisting equipment is not included as the shafts are considered to be subcontractor constructed. The shafts are of a circular configuration with concrete lining. The rate of shaft sinking varies from 1.05 to 1.59 meters per day. The shafts are sized to handle a large man and equipment cage with counterweight and a balanced production hoist. One shaft is used for men and materials for all mine sizes. One or two additional shafts are used to obtain capacity for the larger production operations. The shaft cost includes the station and the skip pocket. The user should not consider shafts of under 100 meters or over 1,000 meters.

The labor costs are inclusive of all labor required for sinking the shafts including supervision.

Supplies include 47% concrete lining, 38% shaft equipment, 10% blasting supplies and 5% drill steel and bits.

Equipment operation is the costs for operating the shaft sinking plant including the hoist, compressors, generators, drills and concreting equipment. Equipment operation costs consist of depreciation or rental of equipment 42%, repair parts 51%, fuel and lubrication 4%, and tires 3%.

The costs for the access shafts are determined by multiplying the depth of shaft in meters by the selected production rate in metric tons per day to obtain metric ton meters per day. This value is used to enter the curve and determine the cost elements in dollars.



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4.1.1.2. ACCESS SHAFTS
CAPITAL COST

4.1.1.3. ACCESS INCLINES

The cost of access inclines is based on subcontractor construction and on one entry 5.5 meters by 6 meters in cross section. It is intended to contain a roadway and conveyor belt. The cost of the conveyor is not included, but may be obtained from Section 4.1.3.3., Conveyor Equipment. The inclination of the entry is set at 15° to accomodate conveyor movement of coarse oil shale. The curves are based on a sinking rate of 2.7 meters per day.

The labor curve is inclusive of all labor cost incurred in sinking the incline including supervision and administration.

Supply costs include 69% ground support materials, 17% explosives and 14% ventilation and utility lines.

Equipment operation includes, 10% fuel and lubrication, 13% tires, 17% repair parts and 60% for depreciation or rental of all equipment.

The cost for the access inclines is determined by entering the curve with the vertical difference between the collar and bottom in meters and then determining the cost elements in dollars.

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Manual estimating method through use of equations, factors and curves for preparation of feasibility/conceptual type estimates for capital and operating costs of oil shale projects. Mining, retorting, modified in situ, upgrading and transportation are included in the handbook. The treatment is limited to the oil shales of Colorado, Utah and Wyoming. Major surface retorting methods are included plus two in situ schemes. User should have basic estimating knowledge with familarity with mining and petroleum processes or related industries. The handbook may be used to evaluate oil shale projects with proposed production rates of 1,500 to 24,000 cubic meters per day of syncrude.

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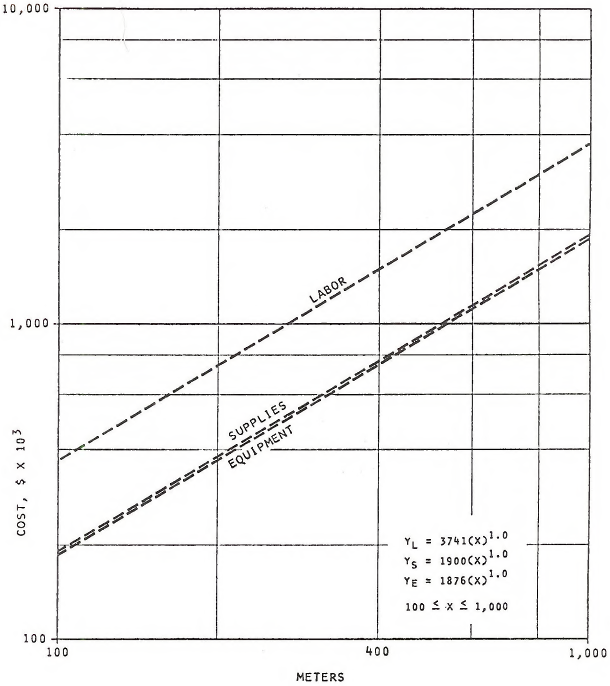

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4.1.1.3. ACCESS INCLINES
CAPITAL COST

4.1.2. MINE FACILITIES

Mine facilities consist of the ventilation system and the surface buildings. The repair facilities and main warehousing are placed underground. Capital costs for this are included in Section 4.1.3.1., Excavation Equipment. The mine will be in close proximity to the retort and will obtain utilities from the processing plant. The mine facilities construction is by subcontract.

4.1.2.1. VENTILATION SYSTEM

The ventilation system has curves for both adit and shaft type access. The ventilation system is sized for diesel powered equipment with 2.12 cubic meters per minute being provided per rated horsepower and 2.83 cubic meters per minute per man. In addition, a 50% leakage factor is included. Shaft sinking rates of from 1.05 to 1.75 meters per day were used.

4.1.2.1.1. SHAFT VENTILATION

The ventilation system requiring shafts includes the cost of the shafts as well as the cost of the fan. Shaft sinking by conventional means only is considered. Surface drilling (blind boring) or raise boring methods are feasible in the oil shale strata but are not included in this handbook. The cost of ventilation is significantly affected by the depth of the ventilation shafts and by the rate of production.

The labor curve is for the labor cost incurred in the sinking of the ventilation shafts.

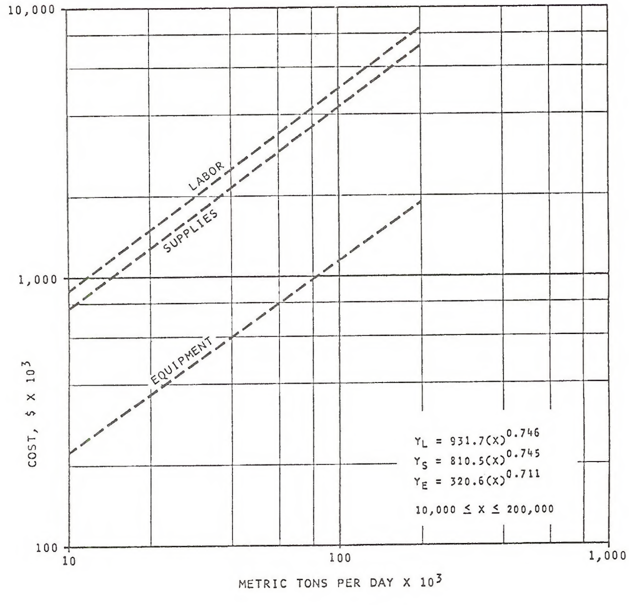
The supplies curve covers construction materials and contains concrete lining 53%, blasting supplies 20%, utilities 21%, and drilling materials 6%.

The equipment operation curve contains fuel and lubrication 4%, repair parts 33% and depreciation or rental of equipment 63%.

These costs are for a working depth of 300 meters and must be adjusted for other depths as follows:

Labor, $F = D/300$
Supplies, $F = D/300$
Equipment operation, $F = 0.624(D/300)$

Where:
F = Factor
D = Depth in meters



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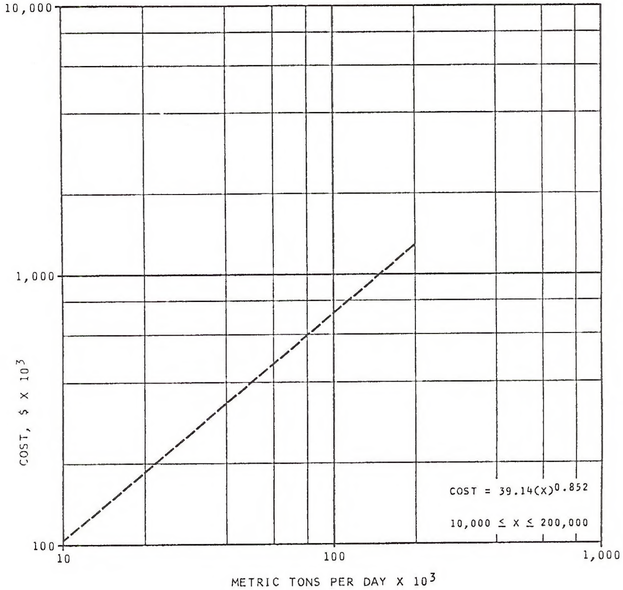
4.1.2.1.1. SHAFT VENTILATION
CAPITAL COST

4.1.2.1.2. ADIT VENTILATION

The adit ventilation curve is for the fan installation with airways being provided by the mine development work.

The cost is composed of 25% construction labor, 5% construction materials and 70% purchased materials.



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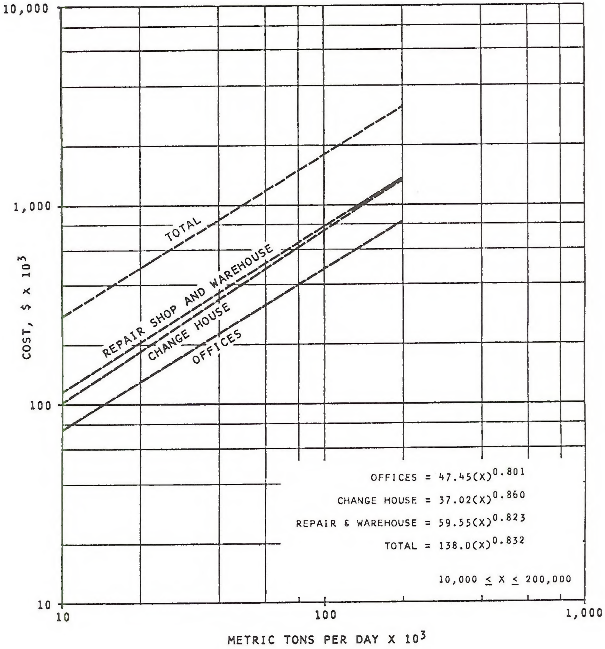
4.1.2.1.2. ADIT VENTILATION
CAPITAL COST

4.1.2.2. SURFACE BUILDINGS

The surface warehouse and repair shop are for service to the surface plant, and as shipping and receiving for the underground operation. The office is for the mine only and includes separate security, fire and safety facilities. The change house is provided for the use of the mine personnel. All facilities are fully equipped.

The main repair facilities and warehousing are located underground adjacent to the main haul or shaft station. The costs for these underground facilities are included in Section 4.1.3.1., Excavation Equipment.

The cost is composed of 25% construction labor, 17% construction materials and 58% purchased equipment.



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4.1.2.2. SURFACE BUILDINGS
CAPITAL COST

4.1.3. MINE EQUIPMENT

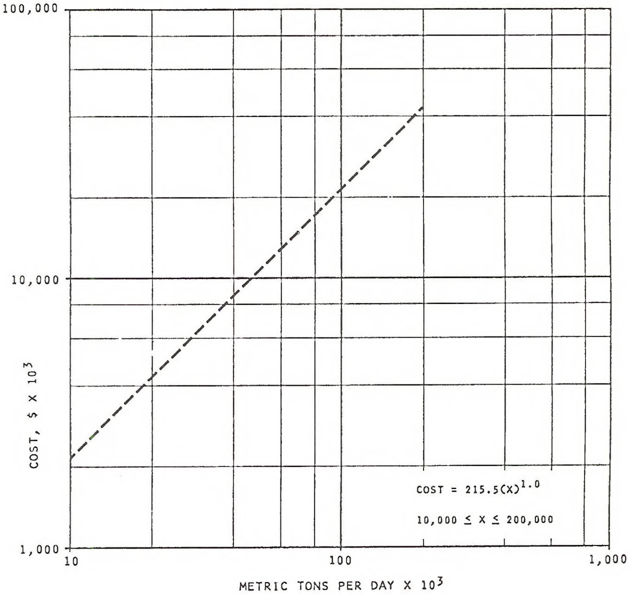
Mine equipment includes all equipment used in the excavation and servicing of the mining operation. Hauling equipment that is dependent on distance as well as production has separate curves in this section.

4.1.3.1. EXCAVATION EQUIPMENT

Excavation equipment includes administrative, face, mine services and maintenance equipment. The equipment is directly related to the production rate of the mine. Due to the large mining faces available, variation in production is obtained by varying the number of units rather than varying the capacity of the units.

The cost of the underground repair facilities and warehousing are included in this section. The cost of truck hauling equipment to provide the initial 1,000 meters of haul from the face is also included. If the haul is less than 1,000 meters, use Section 4.1.3.4., Truck Hauling Equipment, to reduce costs.

The cost is composed of 9% construction labor, 2% construction materials and 89% purchased equipment.



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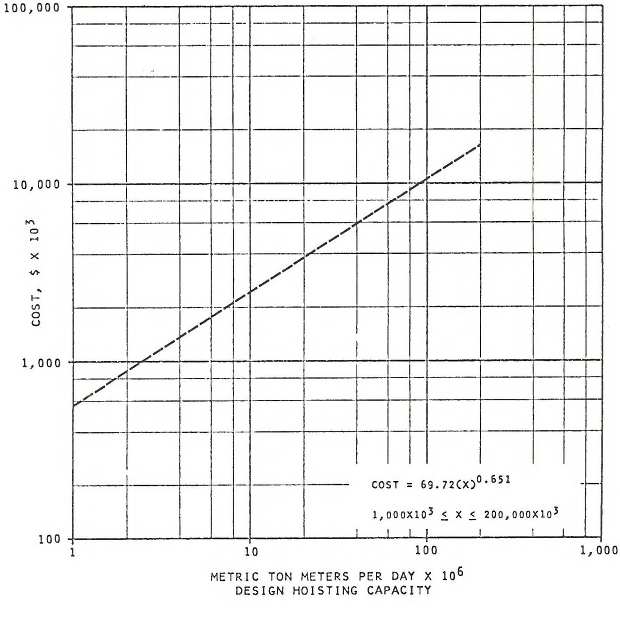
4.1.3.1. EXCAVATION EQUIPMENT
CAPITAL COST

4.1.3.2. HOISTING EQUIPMENT

Hoisting equipment consists of the hoist, electrical equipment, hoist rope, skips, cages, headframe, and hoist house. The hoist equipment is based on balanced hoisting for production hoists. A counterweight and cage are used for service hoists. Friction type hoists were used for all installations. The hoisting equipment cost should be limited to a shaft depth minimum of 100 meters and a maximum of 1,000 meters. Multiple units are used in the cost development when depth and capacity dictate.

To enter the curve select the production rate in metric tons per day and multiply by the production shaft depth in meters.

The cost is composed of 15% construction labor, 10% construction materials and 75% purchased equipment.



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4.1.3.2. HOISTING EQUIPMENT
CAPITAL COST

4.1.3.3. CONVEYOR EQUIPMENT

Conveyors may be used in lieu of or in addition to truck haul either above or below ground. The conveyor cost includes the belt, frame, drive, pulley, rollers and terminal. Installation is included on a prepared roadway.

Determination of the conveyor equipment cost requires the selection of a length of conveyor, conveyor capacity in metric tons per day (eighteen hour day), and inclination of the conveyor for positive inclines. Decline conveyors are considered to cost the same as horizontal. This assumption is considered conservative in that economies may be realized with regenerative braking and smaller drive units than horizontal configurations.

The haul distance is limited from 10 meters to 1,000 meters per conveyor unit. The user should select the length and capacity per day for each conveyor to be used. To enter the curve use the length in kilometers times the conveyor production rate in metric tons per day for each conveyor.

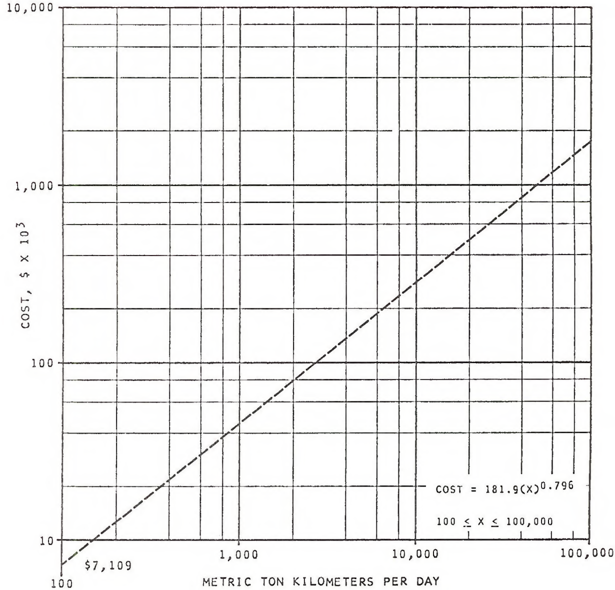
When the conveyor is to be used in an access incline, the conveyor inclination is set at 15° due to the limitations imposed by the access incline configuration. (See Section 4.1.1.3., Access Inclines)

Adjustment for inclination is made by determining the cost for the conveyor in the horizontal configuration and applying the following factor:

$$F = 1+(0.0180)(R)$$

Where:
F = Incline factor
R = Inclination in degrees*

* In the case of decline conveyor, use the horizontal costs without adjustment.



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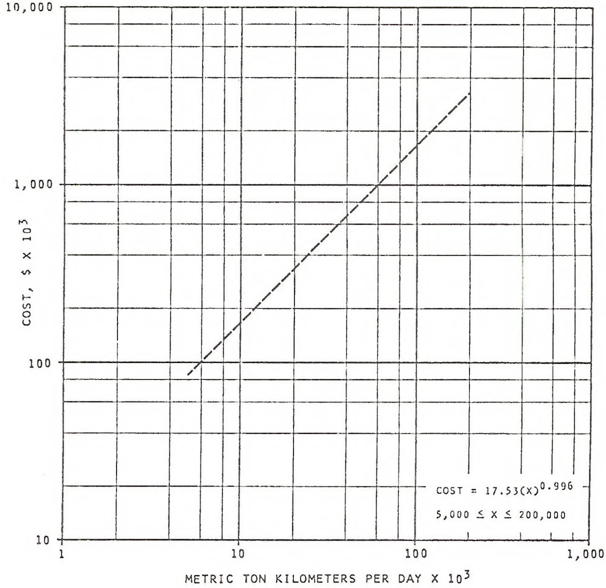
4.1.3.3. CONVEYOR EQUIPMENT
CAPITAL COST

4.1.3.4. TRUCK HAULING EQUIPMENT

Trucks are provided to complete the haul from the 1,000 meters-face area to the primary crusher. The truck haul presumes a horizontal profile which is applicable to underground oil shale mining.

To enter the curve, select the length of haul in kilometers and multiply by the quantity moved in metric tons per day.



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4.1.3.4. TRUCK HAULAGE EQUIPMENT
CAPITAL COST

4.1.3.5. MINE DRAINAGE AND DEWATERING

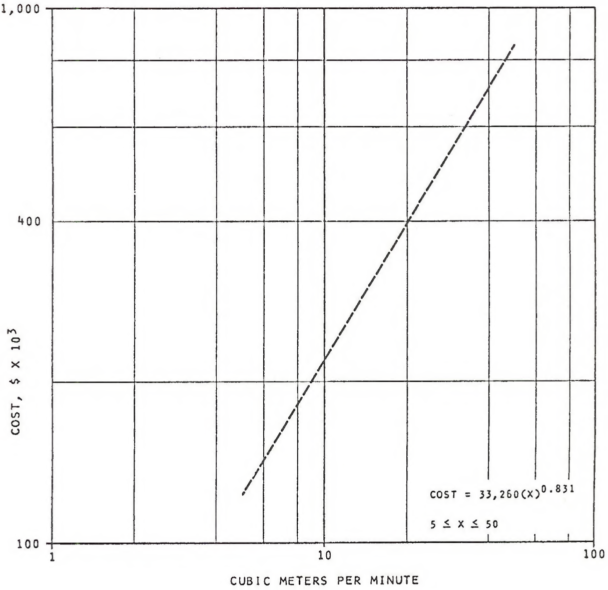
Mine water drainage and dewatering costs are directly dependent on the water inflow quantity. No correlation to other mining parameters is possible for this item. The quantity of inflow must be estimated from hydrological data obtained on the site of interest. A maximum of 50 cubic meters per minute was considered the upper limit for the area covered by this handbook. A lower limit of 5 cubic meters per minute was selected and should be used as the cost for all smaller quantities.

The capital cost curve is based on pumping water vertically from the mine against a total head of 350 meters. The cost is distributed to pumps, pipe, valves, check valves and electrical equipment 76%, construction labor 15% and construction materials 9%.

Based on 100 meters of head minimum, the curve values should be adjusted by the following factor:

$$F = 1+[0.700\times10^{-3}(H-350)]$$

Where:
F = Factor
H = Total head



SCALE - LOGARITHMIC

4.1.3.5. MINE DRAINAGE AND DEWATERING CAPITAL COST

4.2. OPERATING COSTS

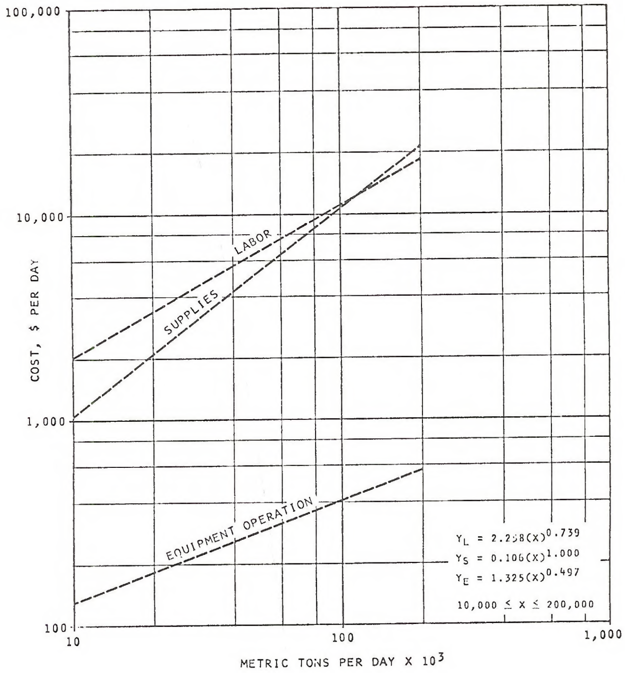
Operating costs consist of labor, supplies and equipment operation used in the operation of the mine. They are based on the metric tons per day production rate. Equipment operation is based on seven hours per shift with the exception of hoisting which is set at six hours per shift. Labor costs are calculated on the basis of eight and one half hours per shift for underground work. The additional half hour is for travel time and is based on current practives.

4.2.1. GENERAL OPERATIONS

The general expense item covers tasks not attributable to a specific mine operation. Included is delivery of materials and supplies, maintenance of roads, service and maintenance of communications, electrical maintenance, sanitation and other non routine housekeeping tasks.

The supplies curve consists of miscellaneous industrial materials.

The equipment curve is composed of repair parts 42%, tires 12% and fuel and lube 46%.



SCALE - LOGARITHMIC

4.2.1. GENERAL OPERATIONS
OPERATING COST

4.2.2. MINE FACILITIES

4.2.2.1. VENTILATION SYSTEM

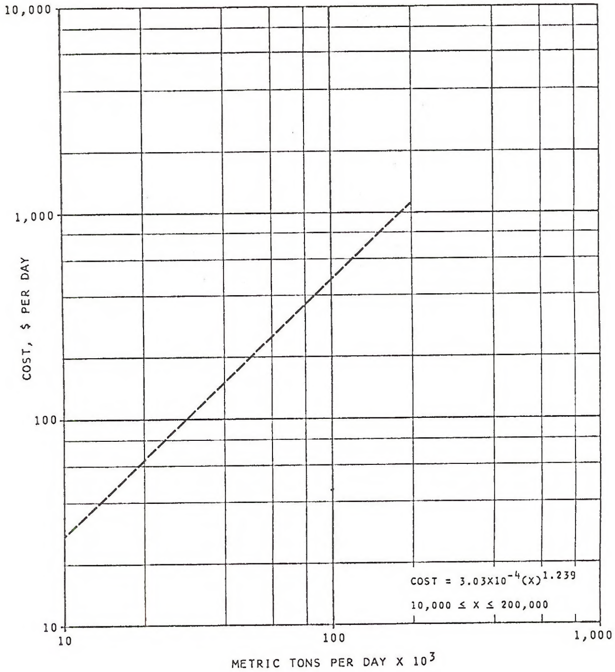
The curve for the ventilation system is for electric power 94%, repair parts 3% and lube 3%. Operating and repair labor are included in the mine services.

The curve is for a main level depth of 500 meters. Adjustment for other depths of operations may be made by multiplying the curve value by the following factor:

$$F = 1.507(H)^{-0.066}(T)^{-1.239}(T)^{0.875}(H)^{0.056}$$

Where:
F = Factor
H = Depth of main level below the surface in meters
T = Production rate in tons per day.

For mines with portal access or less than 100 meters depth, use $H = 100$.
Therefore $F = 1.112(T)^{-0.107}$



SCALE - LOGARITHMIC

4.2.2.1. VENTILATION SYSTEM
OPERATING COST

4.2.3. MINING

The mining operation consists of excavation, hauling and dewatering. Hauling costs are for moving the oil shale from the face area to the surface. Costs are provided for movement of material by vertical hoisting, conveyors or truck. In each case it is necessary to know the tons per day moved and the distance involved.

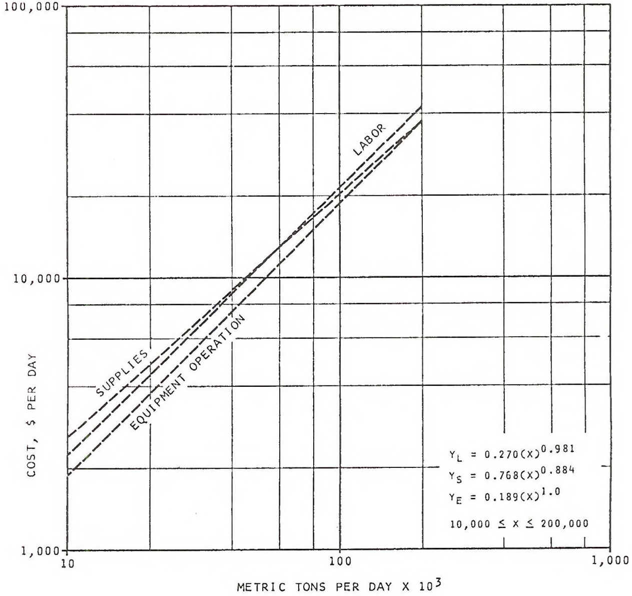
4.2.3.1. MINE EXCAVATION

Mine excavation includes development headings, panel headings, and benches. Labor, supplies, and equipment operation and maintenance costs are included. Excavation costs are based on a drill and shoot sequence, with front end loaders for mucking. Hauling is by rear dump trucks. The cost of the initial 1,000 meter haul is included. If the average haul distance is known, an adjustment may be made by referring to Section 4.2.4.3., Truck Hauling.

Labor includes drillers, loading machine operators, powdermen, roof bolters, scalers, truck drivers and section foremen.

Supplies include 59% blasting agents, and 41% rock bolts, drill steel and bits.

Equipment operation includes fuel and lubrication 38%, tires 30%, and repair parts 32%. Major equipment items are face drills, bulk powder trucks, wheel loaders, bench drills, hydraulic scalers, rear dump trucks and rock bolters.



SCALE - LOGARITHMIC

4.2.3.1. MINE EXCAVATION
OPERATING COST

4.2.4. HAULING

4.2.4.1. HOISTING

Hoisting costs are for transporting both men and materials and oil shale production. One hoist is used for men and materials over the range of production rates considered. One or more additional production hoists are operated to obtain the required production rate. All hoists considered are multi-rope friction hoists with skips in balance or a cage and counterweight. Tail ropes are included in all instances.

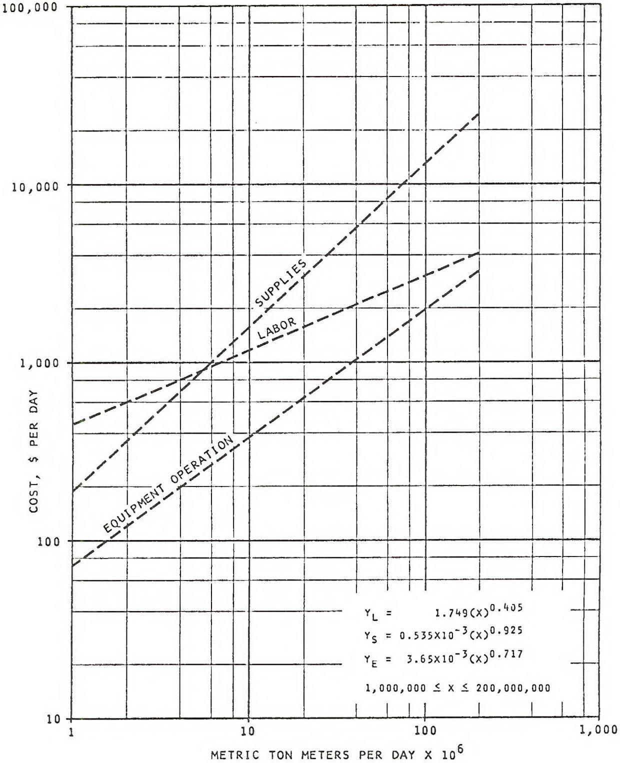
Labor includes hoistmen, skiptenders, cagers and general labor.

Supplies include 75% electric power, 25% hoist ropes for production with a three year replacement, and hoist ropes for men and materials with a four year replacement. The tail ropes are considered operable for the life of the installation.

Equipment operating costs are distributed 9% fuel and lube and 91% repair parts.

To determine the hoisting costs, select the mine production rate per day, and multiply by the depth to the main level in meters. Enter the curve with this value and determine the cost per day in dollars.

This depth should be limited to a minimum of 100 meters with a maximum of 1,000 meters.



SCALE - LOGARITHMIC

4.2.4.1. HOISTING
OPERATING COST

4.2.4.2. CONVEYOR HAULING.

Conveyor operation consists of maintenance labor, power, repair parts and lubes. The conveyor belt is considered operable for the life of the installation.

The labor curve is for operating, maintenance and repair labor.

The supply curve is the cost of electric power.

Equipment operation is 95% repair parts and 5% lubrication.

The haul distance is limited from 10 meters to 1,000 meters per conveyor unit. The user should select the length and capacity per day for each conveyor to be used. To enter the curve use the length in kilometers times the conveyor production rate in metric tons per day for each conveyor.

To obtain the cost for incline conveyors, use the following factors:

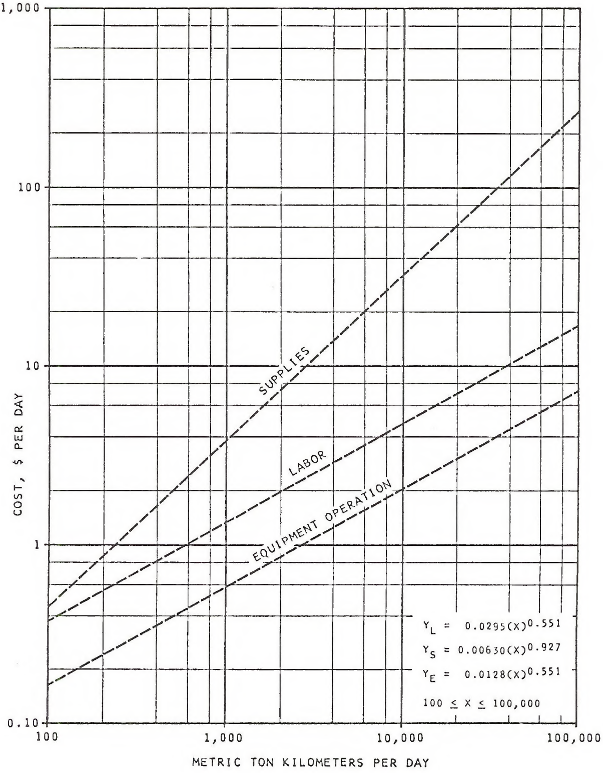
Labor, $F = 1+[0.0817(R)]$

Supplies, $F = 1+[0.375(R)]$

Equipment operation, $F = 1+[0.0911(R)]$

Where:
F = Factor
R = Incline in degrees*

* In the case of decline conveyor, use the horizontal costs without adjustment.



SCALE - LOGARITHMIC

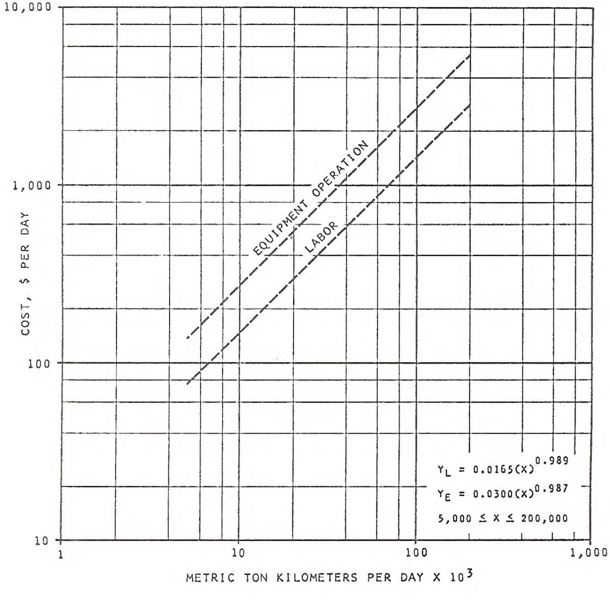
4.2.4.2. HORIZONTAL CONVEYOR HAULING
OPERATING COST

4.2.4.3. TRUCK HAULING

Truck haul costs are provided to cover cost of hauling from the face area to the surface, hoist, or conveyor loading point. Loading or dumping is not included, therefore, these curves must be used as a modification to the Mine Excavation costs. The costs may be adjusted depending on average haul distances.

The truck haul cost is determined by taking the production in metric tons per day and multiplying by the length of haul minus 1000 meters. Loading and dumping operations and 1000 meters of hauling are included in Section 4.2.3.1., Mine Excavation. The equipment and labor costs may then be determined on a cost per day basis.

The equipment operation curve consists of repair parts 20%, fuel and lubrication 37%, and tires 43%.



$Y_L = 0.0165(X)^{0.989}$

$Y_E = 0.0300(X)^{0.987}$

$5,000 \leq X \leq 200,000$

SCALE - LOGARITHMIC

4.2.4.3. TRUCK HAULING
OPERATING COST

4.2.4.4. MINE DEWATERING

The pumping cycle operates 24 hours per day and 365 days per year. Labor consists of pump operators and maintenance labor only. The supply consists of electrical power only and is based on a total pumping head of 350 meters.

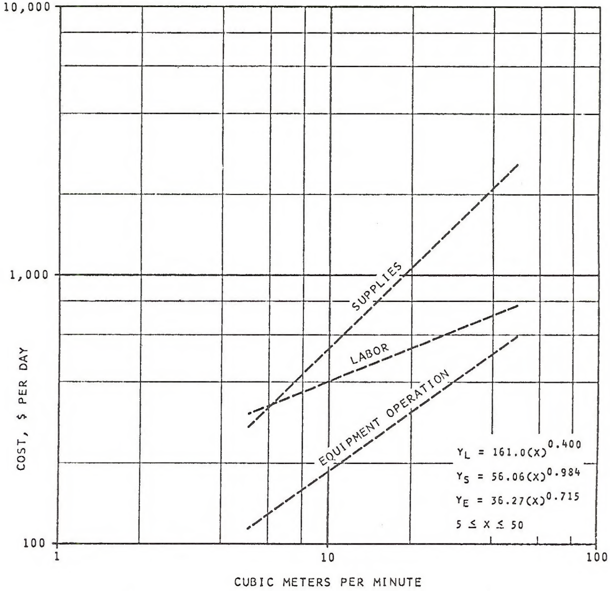
Due to the unknown quality of the water and the final disposition of the mine water, no attempt is made to include a cost for treating the mine effluent in this handbook.

The equipment operation consists of 90% repair parts and 10% lube.

The curve values should be adjusted for other than 350 meter pumping head by the following factor:

$$F = 1+[0.00840(H-350)]$$

Where:
F = Factor
H = Total pumping head in meters. Where pumping head is less than 100 meters, use 100 meters.



SCALE - LOGARITHMIC

4.2.4.4. MINE DEWATERING

OPERATING COST

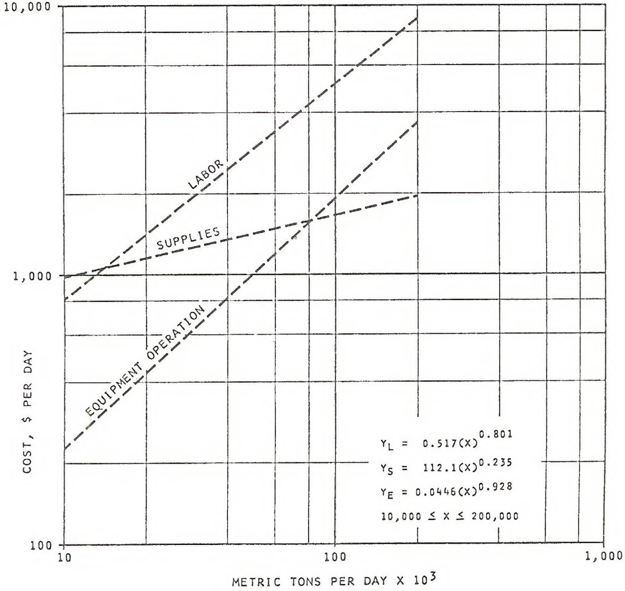
4.2.5. MINE SERVICES

Mine services are those functions performed that are not directly engaged in oil shale production. The services are provided by crews working in support of all mining sections. Activities include construction of ventilation stoppings, roadway maintenance, repair shop operation, roof maintenance, and utilities operation.

Labor includes miners, electricians, equipment operators, mechanics, lampmen, warehousemen and foremen.

Supplies are industrial materials including stopping curtains, water pipe, drain pipe, lighting and communications hardware.

Equipment operation is for 43% tires, 37% fuel and lubrication, and 20% repair parts for the vehicles used in mine services. These vehicles include water trucks, scissor trucks, motorgraders and flatbed trucks.



SCALE - LOGARITHMIC

4.2.5. MINE SERVICES
OPERATING COST

4.2.6. GENERAL EXPENSE

General expenses are those costs incurred by the management, technical and administrative operations. Costs are limited to the mine requirements. Home office or other corporate expenses are not considered.

4.2.6.1. ADMINISTRATIVE SALARIES

Administrative salaries are for the management, technical and administrative personnel. Included are the mine manager, engineers, geologists, office group, safety, security, and maintenance and mine top level supervision. Salaries do not include an allowance for burden. Most administrative personnel are not covered by the same fringe benefits as mine workers and an allowance of 25% will cover burden. However, if they are to be covered the same as mine workers, then use 35%.

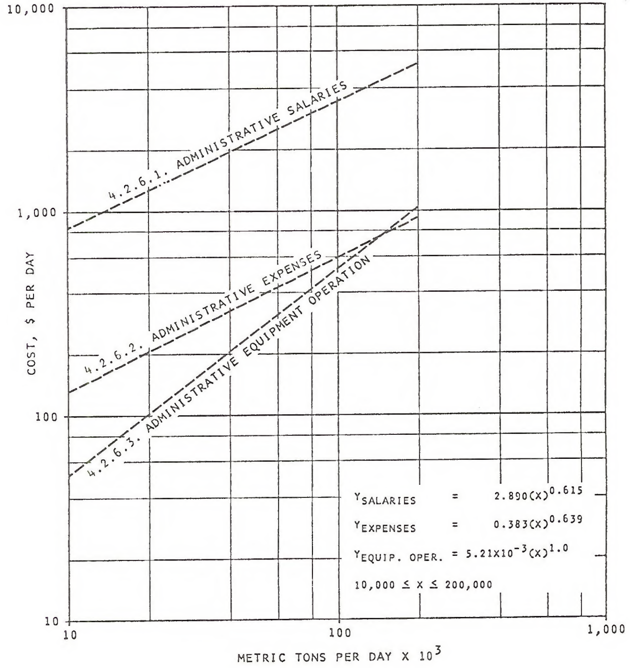
4.2.6.2. ADMINISTRATIVE EXPENSES

Administrative expenses covers office, engineering, safety and first aid supplies and expenses, such as communications, travel, miscellaneous fees, dues, donations, computer services, etc. Also included is a small tool allowance.

4.2.6.3. ADMINISTRATIVE EQUIPMENT OPERATION

Administrative equipment consists of sedans, pickup trucks, ambulances, fork lifts and flat bed trucks used by the administrative personnel. Capital cost of this equipment is included in Section 4.1.3.1., Excavation Equipment.

Administrative equipment operation includes 5% tires, 62% fuel and lubrication and 33% repair parts for the administrative equipment.



SCALE - LOGARITHMIC

4.2.6. GENERAL EXPENSES
ADMINISTRATIVE - OPERATING COST

5. OPEN PIT MINING

Open pit (surface) mining is based on a combined production rate of overburden and oil shale ore of from 20,000 minimum to 400,000 maximum metric tons per day. The curves presented in this section are in some cases for only overburden or ore production and have designated limits of from 10,000 minimum to 200,000 maximum metric tons per day. The user must determine the distribution of the overburden to ore except at the limits where the distribution is 50% to each.

To determine the quantity per day to be mined, see method described in Section 4., Underground Mining.

5.1. CAPITAL COSTS

5.1.1. PREPRODUCTION DEVELOPMENT

5.1.1.1. PREPRODUCTION CLEARING

The curve for clearing during preproduction development is based on estimated costs for medium light growth on terrain with a side slope of 0 to 30%. Estimate one tree, 0.33 meters in diameter, per 200 square meters.

The curve is valid between the limits of 10 to 750 hectares. For total clearing area in excess of 750 hectares, the clearing rate will remain constant at the rate determined for 750 hectares.

For light clearing consisting mainly of brush and small trees, the costs would be reduced by 75% from those shown for medium clearing. For heavy clearing, the cost should be increased 75% over those shown for medium clearing.

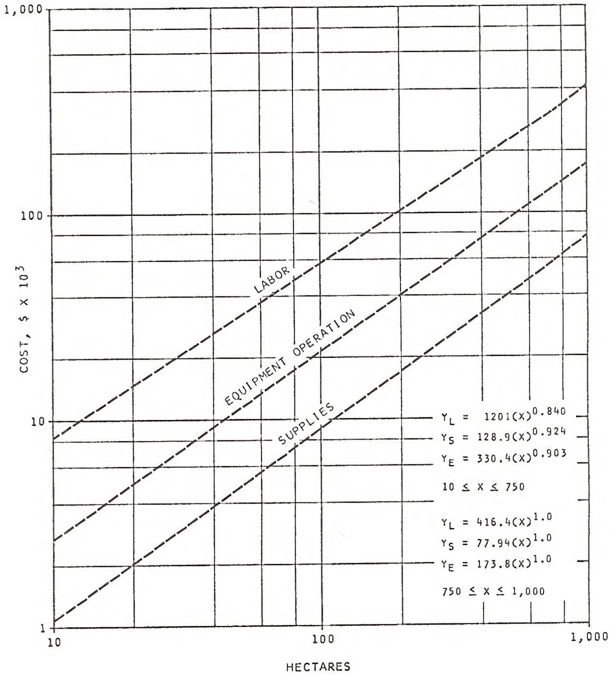
For terrain over 30% up to 100% side slope, costs should be increased 20%. On rocky slopes and slopes over 100%, cost could double or triple and the user should use his own judgement.

The labor cost curve includes dozer operators, laborers, and equipment repair labor.

Supply costs are 57% fuel oil for burning and 43% for tools, cable, chokers, etc.

Equipment operating cost is distributed repair parts 60%, fuel and lubrication 39% and tires 1%.

Text continued on page 60.



SCALE - LOGARITHMIC

5.1.1.1. CLEARING
CAPITAL COST

5.1.1.1. PREPRODUCTION CLEARING Continued

The curves are based on using owner supplied equipment available from the excavation equipment.

Where it is necessary to purchase equipment or have a subcontractor perform the work, multiply the equipment operation value by the following applicable factor in order to obtain the total value of equipment expense for ownership and operation:

Shifts per Day	1	2	3
Factor	1.75	1.56	1.50

If a subcontractor is used, multiply labor by 1.50, supplies by 1.20, and equipment expense by 1.20 to compensate for subcontractor's markup.

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5.1.1.2. PREPRODUCTION TOPSOIL REMOVAL

The curves for common excavation of topsoil represent costs for scraper excavation including support operations such as dozing, pushing and road maintenance. The curves cover a range of excavation from 1,000 cubic meters per day using 13 short ton self-loading scrapers to 30,000 cubic meters per day using 38 short ton self-loading scrapers. The curves are based on an average level haul length of 900 meters one way. A change in haul length or grade will result in a change in unit cost. To determine the unit costs for varying haul lengths and grades, multiply the costs obtained from the curves by the following factors:

Labor Factor,
$F = 0.0501(L)^{0.440}(G)^{1.530}$

Equipment Operating Factor,
$F = 0.0274(L)^{0.529}(G)^{1.620}$

Where:
F = Factor
L = Length of haul in meters
G = Grade (defined as 1.0 ± (%grade/100))

Production is in cubic meters per day and is based on a material less than one meter thick, having a weight of 1.8 metric tons per cubic meter and which does not require ripping the user must determine both his production per day and the total volume of topsoil to be removed during the preproduction phase.

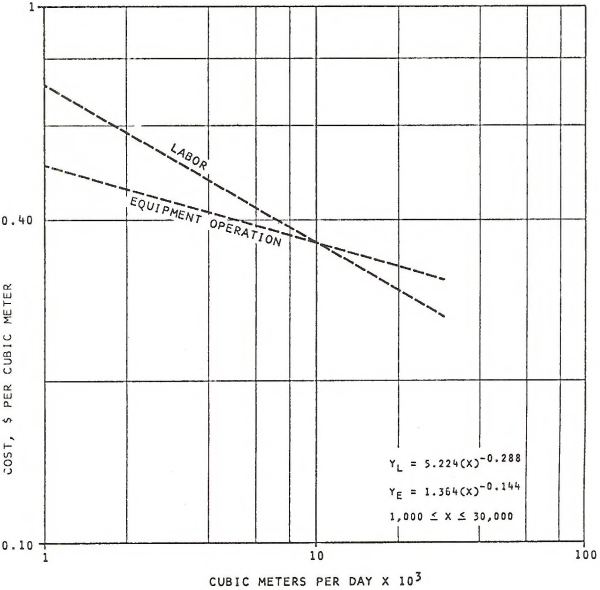
The labor cost curves include foreman, scraper operators, dozer operators, road maintenance equipment operators, plus equipment repair labor.

The equipment operating cost is distributed repair parts 48%, fuel and lubrication 28% and tires 24%.

Where it is necessary to purchase equipment or have a subcontractor perform the work, multiply the equipment operation value by the following applicable factor in order to obtain the total value of equipment expense for ownership and operation:

Shifts per Day	1	2	3
Factor	2.05	1.79	1.70

If a subcontractor is used, multiply labor by 1.50 and equipment expense by 1.20 to compensate for subcontractor's markup.



SCALE - LOGARITHMIC

5.1.1.2. PREPRODUCTION TOPSOIL REMOVAL
CAPITAL COST

5.1.1.3. PREPRODUCTION DRILL AND BLAST - OVERBURDEN

The curves for drilling and blasting overburden represent the cost for drilling, loading and blasting plus secondary blasting of 5% of the daily production. The curves are for overburden production rates of 10,000 to 200,000 metric tons per day.

The costs for drilling and blasting are based on the following criteria:

1. The overburden has a bank weight of 2.6 metric tons per cubic meter.

2. A powder factor of 0.177 kg per metric ton is required.

3. The overburden will be dry permitting the use of ANFO blasting agent.

4. Drilling is performed using rotary drills and tricone bits. Rotary drills vary in size from 41,000 kg down pressure with 9-7/8" (25.08 cm) bits to 50,000 kg down pressure with 15" (38.10 cm) bits.

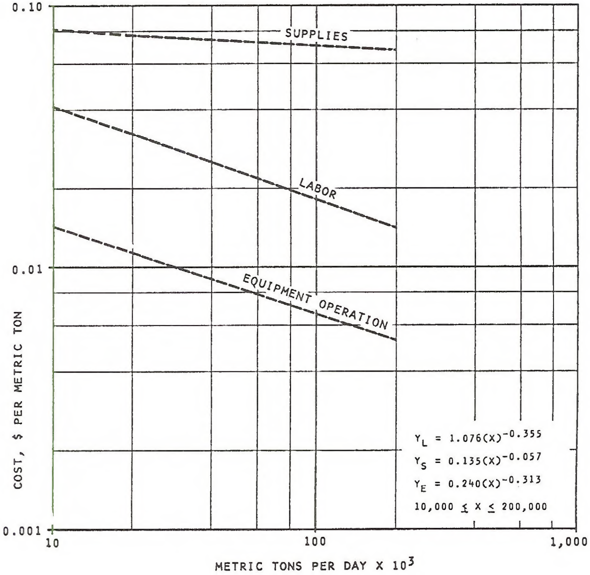
5. Benches are 15 meters high, holes are drilled to a depth of 17.5 meters and are loaded to a depth of 10.5 meters. Drill patterns vary from 7 meters by 8.5 meters for 9-7/8" (25.08 cm) holes to 10.5 meters by 12 meters for 15" (38.10 cm) diameter holes.

The labor curve includes a drill foreman, drillers and helpers, powdermen and helpers, powder and service truck drivers, plus trac driller and chucktender for secondary drilling.

The supplies curve includes rotary bits 10% and powder and blasting supplies 90%.

The equipment operation cost is distributed repair parts 44%, fuel and lubrication 54% and tires 2%.

Text continued on page 66.



SCALE - LOGARITHMIC

5.1.1.3. PREPRODUCTION DRILL AND BLAST - OVERBURDEN
CAPITAL COST

Where the overburden is wet, and slurry is required in lieu of ANFO, the labor and equipment operation costs will not change. The supplies costs will be twice that shown on the curves as a result of a increase in the cost of the slurry as compared to ANFO.

Where it is necessary to purchase equipment or have a subcontractor perform the work, multiply the equipment operation value by the following applicable factor in order to obtain the total value of equipment expense for ownership and operation:

Shifts per Day	1	2	3
Factor	3.20	2.65	2.47

If a subcontractor is used, multiply labor by 1.50, supplies by 1.20, and equipment expense by 1.20 to compensate for subcontractor's markup.

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5.1.1.4. PREPRODUCTION LOAD AND HAUL - OVERBURDEN

The curves show the cost per metric ton for loading and hauling overburden, either common or shot rock, from a pit 90 meters in depth for overburden production rates ranging from 10,000 to 200,000 metric tons per day. One bank cubic meter equals 2.6 metric tons.

The costs for loading and hauling overburden are based on the following criteria:

1. Loading is performed with electric shovels ranging in size from 11 cubic yard capacity to 25 cubic yard capacity.

2. Benches in the pit are 15 meters in height.

3. Hauling is with rear dump trucks ranging in size from 85 ton to 170 ton capacity.

4. Haul roads out of the pit are on a grade of +8% to the pit rim and then ± 5% to a dump 4,300 meters one way from the loading unit.

5. Rubber tired wheel dozers and front end loaders are used to maintain the loading area and support the loading operations.

6. Crawler dozers are provided at the dump.

7. A water truck and grader will maintain the haul road.

The cost curves reflect an average ratio of 8 trucks per shovel for the required production based on the above criteria. To determine costs for hauls of varying length or depth of pit, multiply the costs obtained from the curves by the following factors:

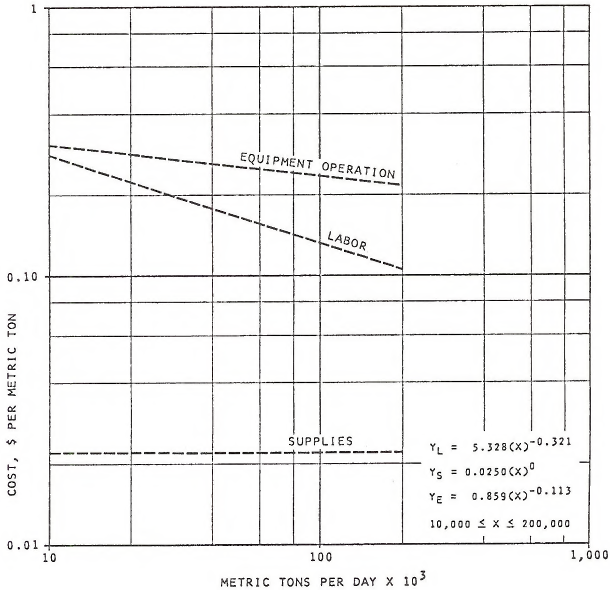
Labor Factor, $F = 0.0967(R)^{0.030}(L)^{0.263}$

Equipment Factor, $F = 0.0422(R)^{0.047}(L)^{0.353}$

Where:
F = Factor
R = Depth of pit in meters (- or 0% grade, R=1.0)
L = Length of haul in meters.

Variation in the haul road grade is a function of the depth of pit and length of haul and is incorporated in the curve.

Text continued on page 70.



SCALE - LOGARITHMIC

5.1.1.4. LOAD AND HAUL - OVERBURDEN
CAPITAL COST

5.1.1.4. PREPRODUCTION LOAD AND HAUL - OVERBURDEN Continued

Labor costs are approximately 70% for operation of equipment and includes pit foreman, shovel operators, oilers, truck drivers, wheel dozer operator, water truck driver, grader operator and dump dozer operator; and 30% for repair labor to maintain equipment.

Supplies costs are for electric power for shovel operation.

The equipment operating cost is distributed repair parts 24%, fuel and lubrication 36% and tires 40%.

Where it is necessary to purchase equipment or have a subcontractor perform the work, multiply the equipment operation value by the following applicable factor in order to obtain the total value of equipment expense for ownership and operation:

Shifts per Day	1	2	3
Factor	2.55	2.16	2.03

If a subcontractor is used, multiply labor by 1.50, supplies by 1.20, and equipment expense by 1.20 to compensate for subcontractor's markup.

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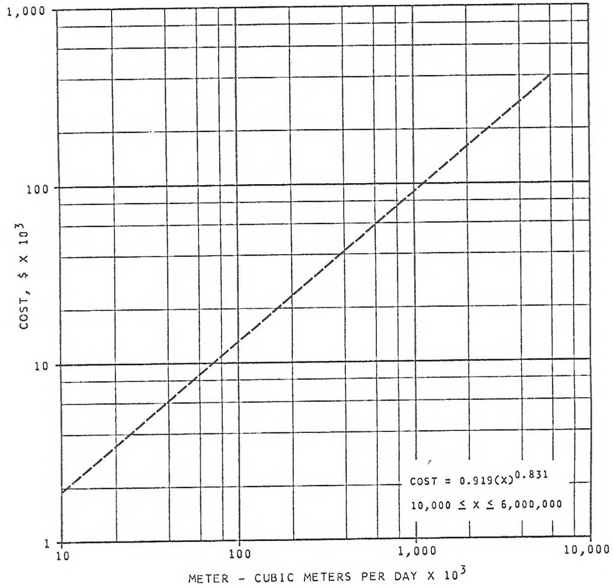
5.1.2. MINE FACILITIES

5.1.2.1. DRAINAGE SYSTEM

The cost of the drainage system is the purchase price of the pumps and piping, and the installation of the equipment. The electric power system to operate the pumps is part of the Section 5.1.2.4., Electrical System. The curve is based on pumping the water from the bottom of the pit to a discharge point at the pit rim.

Construction labor accounts for 27%, purchased equipment 40% and construction materials 33% of the cost.

The required pumping rate in cubic meters per day and the total head of lift in meters must be determined in order to use the curve. The cost may be read directly from the curve when the drainage requirements in meter-cubic meters are known.



SCALE - LOGARITHMIC

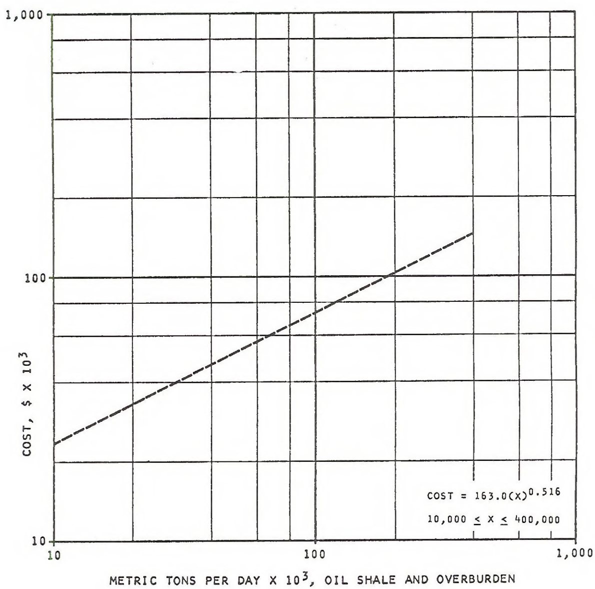
5.1.2.1. DRAINAGE SYSTEM
CAPITAL COST

5.1.2.2. COMMUNICATIONS SYSTEM

The communications system curve is based on installed cost for a radio network and surface telephone service. The radio system contains mobile and base units with one or more repeaters depending on the size of the mine. Telephone service costs are based on a complete telephone system with installation by an outside agency.

For escalation, distribute 80% of the cost to purchased equipment and 20% to labor.

Use total of daily production of oil shale and overburden to enter curve.



SCALE - LOGARITHMIC

5.1.2.2. COMMUNICATIONS SYSTEM
CAPITAL COST

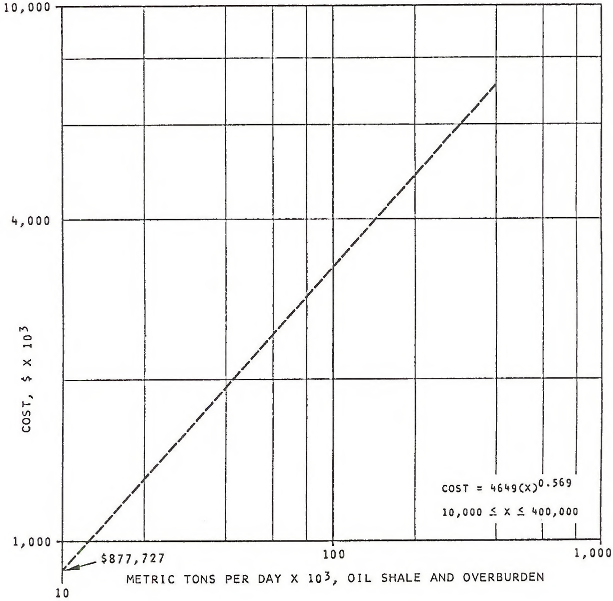
5.1.2.3. BUILDINGS

The costs represented by this curve are for the surface buildings necessary for the support of an open pit operation. Included are offices, repair shops, warehouses, change houses and wash and lube building. Also included are the fueling facilities including mobile units for field service.

For escalation, cost is distributed construction labor 18%, construction materials 61% and equipment 21%.

The curve is for the mine operation and makes no provision for the facilities required by the retort or upgrading operations.

The costs are based on the total material mined consisting of both overburden and oil shale.



SCALE - LOGARITHMIC

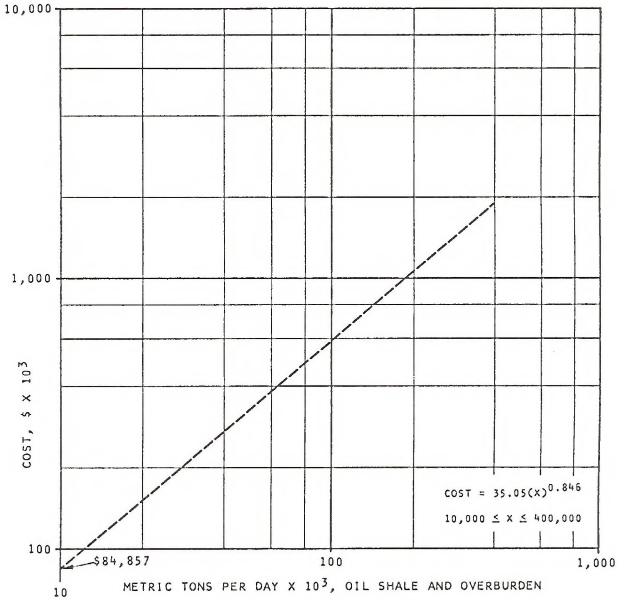
5.1.2.3. BUILDINGS
CAPITAL COST

5.1.2.4. ELECTRICAL SYSTEM

The electrical system curve is based on a mining operation using electric shovels as the principal loading unit. The electrical system includes the main substation, overhead power lines, trailing cables, and portable secondary substations. The electric power lines are presumed to be provided to the main substation by the public utility company.

The cost is based on total material mined consisting of both oil shale and overburden. Sufficient capacity is included in the electrical system for dewatering with electric pumps and ancillary lighting.

For escalation, use construction labor 20% and purchased materials 80%.



SCALE - LOGARITHMIC

5.1.2.4. ELECTRICAL SYSTEM
CAPITAL COST

5.1.3. MINE EQUIPMENT

5.1.3.1. EXCAVATION EQUIPMENT

The following cost curves are for the purchase of surface mine capital equipment covering mines with typical daily production rates from 10,000 to 200,000 metric tons for either oil shale or overburden.

These costs are predicated upon the equipment being delivered and made fully operable. They also include provision for standby equipment, spare parts, administrative and maintenance units and an allowance for miscellaneous items.

Two cost curves are presented for surface mining operations. One curve represents the cost of equipment required for overburden excavation. The other curve represents the cost of equipment required for oil shale excavation.

The curves are based on an assumed haul distance and depth of pit that represents the equipment requirements at the tonnage presented. If the haul distance and depth of pit is known, the following factors may be used.

Overburden, $F = 0.0422(R)^{0.047}(L)^{0.353}$

Oil Shale, $F = 0.0359(R)^{0.047}(L)^{0.353}$

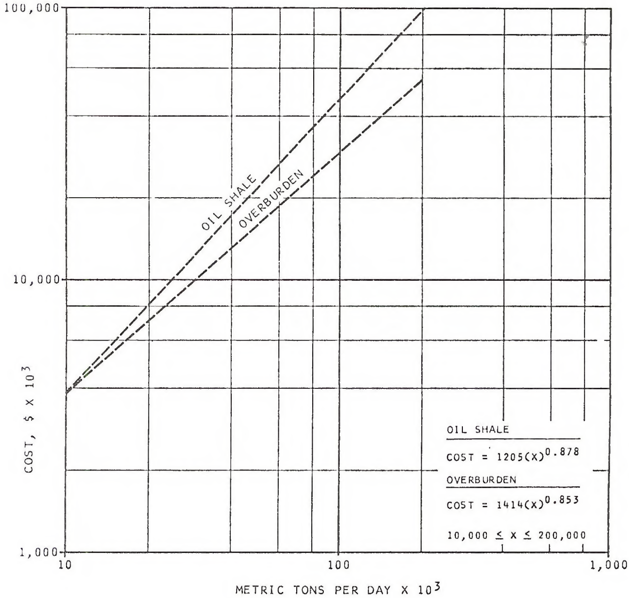
Where:
F = Factor
R = Depth of pit in meters (- or 0% grade, R=1.0)
L = Length of haul in meters

The types of equipment covered in these cost curves include all classes of mobile and stationary machinery regularly found in surface mining, compressors, drills, powder trucks, wheel loaders, shovels, crawler dozers and rippers, on and off highway trucks, pickup trucks and water trucks.

The cost for fixed supporting items such as electric power transmission lines has been covered where specifically noted in other sections.

Capital Cost Distribution

Type Equipment	Overburden & Waste	Oil Shale
Clearing Equipment	2.0%	
Topsoil Removal Equipment	6.5%	
Drill & Blast Equipment	5.5%	5.0%
Loading Equipment	25.5%	26.0%
Hauling Equipment	60.5%	69.0%



SCALE - LOGARITHMIC

5.1.3.1. EXCAVATION EQUIPMENT
CAPITAL COST

5.1.3.2. CONVEYOR EQUIPMENT

Conveyors provide an economical means of handling bulk materials over a set distance and profile. The use of conveyors in the oil shale open pits is quite likely, particularly for movement of the oil shale from a central crusher location in the pit to the processing plant. It is also possible that they would be employed in the overburden disposal system. Conveyor installations of this nature are of specific design; generalization for purpose of estimating provides general costs.

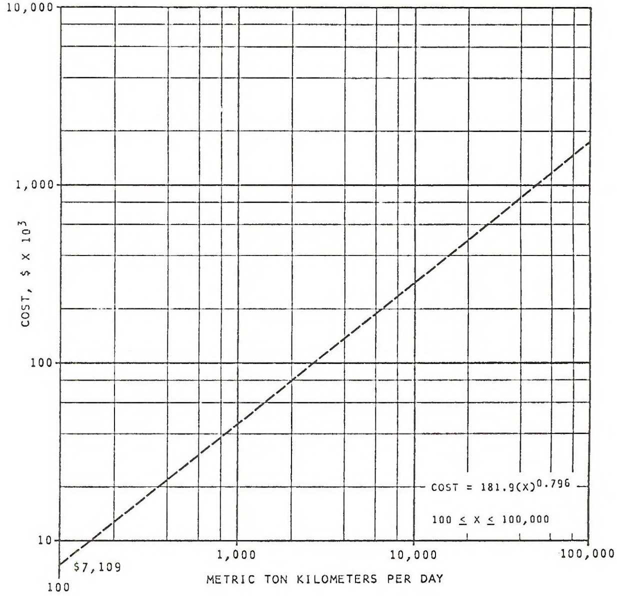
The haul distance is limited from 10 meters to 1,000 meters per conveyor unit. The user should select the length and capacity per day for each conveyor to be used. Multiply the length in kilometers times the conveyor production rate in metric tons per day for each conveyor, and enter the curve on the X-axis with this figure.

Adjustment for inclination is made by determining the cost for the conveyor in the horizontal configuration and applying the following factor:

$$F = 1+(0.0180)(R)$$

Where:
F = Incline factor
R = Incline in degrees*

* In the case of decline conveyor, use the horizontal costs without adjustment.



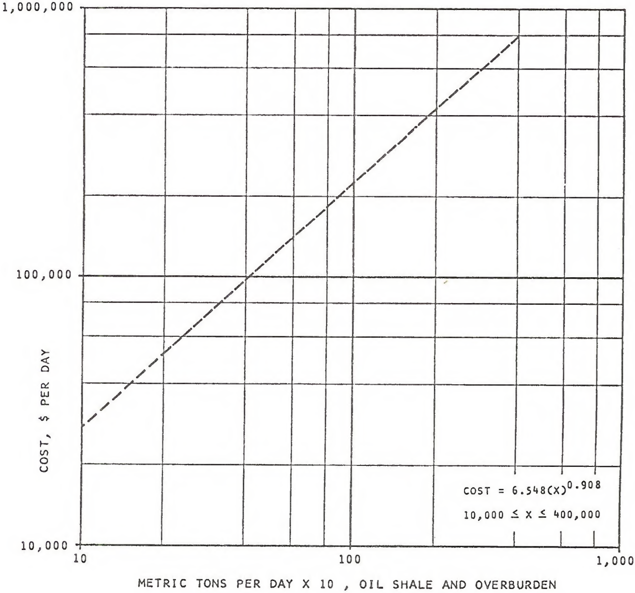
SCALE - LOGARITHMIC

5.1.3.2. CONVEYOR EQUIPMENT
CAPITAL COST

5.1.3.3. ADMINISTRATIVE EQUIPMENT

Administrative equipment consists of the equipment used by the management, engineering, safety, security and fire control personnel. It does not include the shift supervisory personnel or maintenance vehicles which are included with the excavation equipment.

The curve is for the initial purchase of the equipment and is based on the total tonnage of the open pit including overburden and oil shale.



SCALE - LOGARITHMIC

5.1.3.3. ADMINISTRATIVE EQUIPMENT
CAPITAL COST

5.2. OPERATING COSTS

5.2.1. PRODUCTION DEVELOPMENT

The user must determine the number of days to be used for production development which may or may not be the same as used for the mining operation.

5.2.1.1. CLEARING

The curve for clearing production is based on costs for medium light growth on terrain with a side slope of 0 to 30%. Estimate one tree, 0.33 meters in diameter, per 200 square meters.

For light clearing of brush and small trees, the cost is 25% of medium clearing cost curves shown. For heavy clearing, costs should be increased 75% over the curves.

For clearing on terrain with side slopes from 30% to 100%, increase costs 20%. On rocky slopes and slopes over 100%, costs could double or triple and the user should use his own judgement.

The clearing rate may be determined as follows:

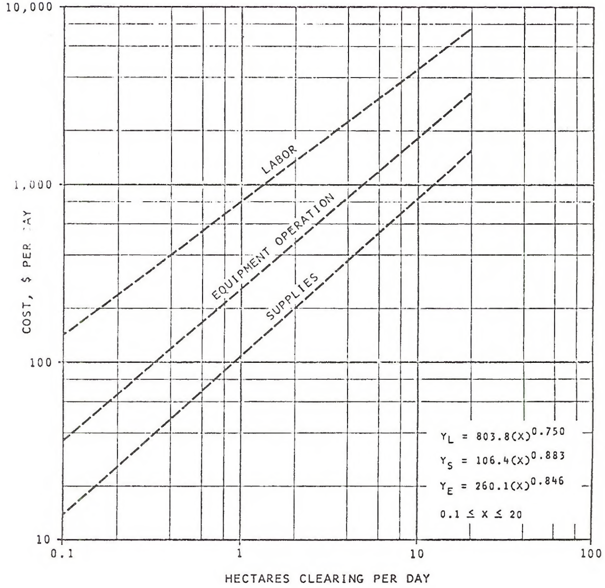
$$C = 0.196(T)^{0.645}$$

Where:
C = Clearing rate in hectares per day
T = Total clearing area in hectares

The labor cost curves include dozer operators, laborers and equipment repair labor.

Supplies consist of 57% for fuel oil and 43% for tools, cables and chokers.

The equipment operating cost is distributed repair parts 60%, fuel and lubrication 39% and tires 1%.



SCALE - LOGARITHMIC

5.2.1.1. CLEARING
OPERATING COST

5.2.1.2. TOPSOIL REMOVAL

The curves for common excavation of topsoil represent costs for scraper excavation including support operations such as dozing, pushing and road maintenance. The curves cover a range of excavation from 1,000 cubic meters per day using 13 short ton self-loading scrapers to 30,000 cubic meters per day using 38 short ton self-loading scrapers. The curves are based on an average level haul length of 900 meters one way. A change in haul length or grade will result in a change in unit cost. To determine the unit costs for varying haul lengths and grades, multiply the costs obtained from the curves by the following factors:

Labor Factor,
$F = 0.0501(L)^{0.440}(G)^{1.530}$

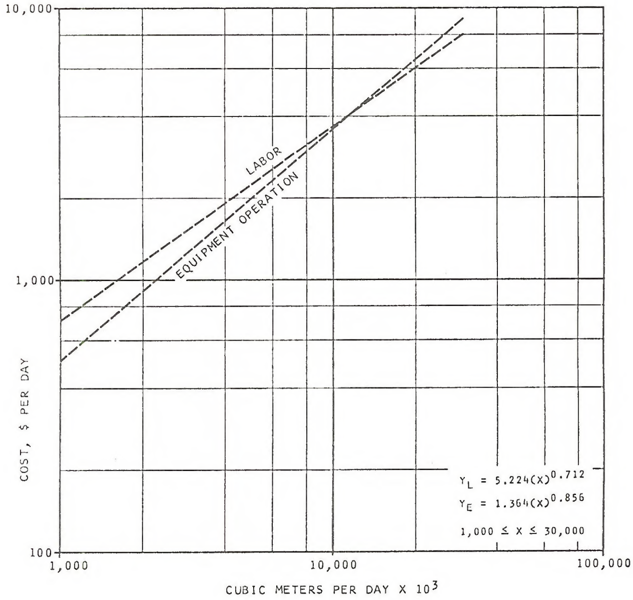
Equipment Operating Factor,
$F = 0.0274(L)^{0.529}(G)^{1.620}$

Where:
F = Factor
L = Length of haul in meters
G = Grade (defined as 1.0 ± (%grade/100))

Production is in cubic meters per day and is based on a material less than one meter thick, having a weight of 1.8 metric tons per cubic meter and which does not require ripping. The user must determine both his production per day and the total volume of topsoil to be removed during the preproduction phase.

The labor cost curves include foreman, scraper operators, dozer operators, road maintenance equipment operators, plus equipment repair labor.

The equipment operating cost is distributed repair parts 48%, fuel and lubrication 28% and tires 24%.



SCALE - LOGARITHMIC

5.2.1.2. TOPSOIL REMOVAL
OPERATING COST

5.2.1.3. DRILL AND BLAST - OVERBURDEN

The curves for drilling and blasting overburden represent the cost per day for drilling, loading and blasting plus secondary blasting of 5%. The production rates range from 10,000 to 200,000 metric tons per day.

The costs for drilling and blasting have been estimated based on the following criteria:

1. The overburden has a bank weight of 2.6 metric tons per cubic meter.

2. A powder factor of 0.177 kg per metric ton will be required.

3. The overburden will be dry permitting the use of ANFO blasting agent.

4. Drilling is performed using rotary drills and tricone bits. Rotary drills vary in size from 41,000 kg down pressure with 9-7/8" (25.08 cm) bits, to 50,000 kg down pressure with 15" (38.10 cm) bits.

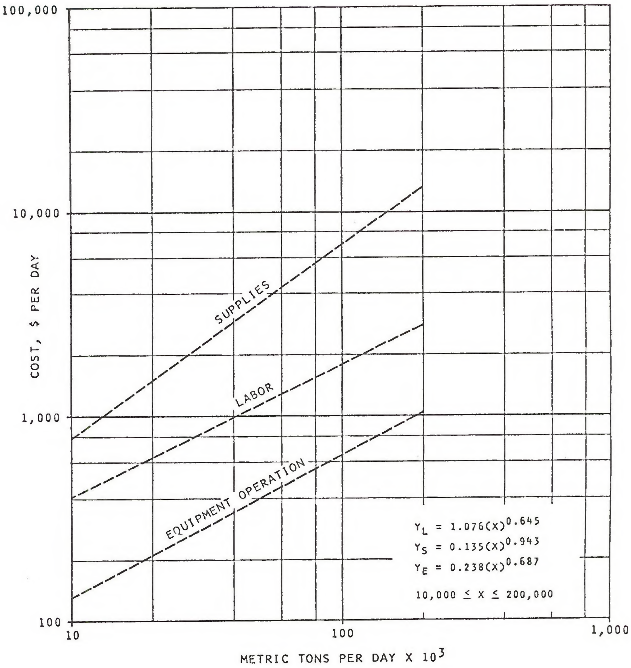
5. Benches will be 15 meters high, holes will be drilled to a depth of 17.5 meters and will be loaded 10.5 meters. Drill patterns vary from 7 meters by 8.5 meters for 9-7/8" (25.08 cm) holes to 10.5 meters by 12 meters for 15" (38.10 cm) diameter holes.

The labor curve includes a drill foreman, drillers and helpers, powdermen and helpers, powder and service truck drivers, plus track driller and chucktender for secondary drilling.

The supplies curve includes rotary bits 10%, powder and blasting supplies 80% and secondary blasting supplies 10%.

The equipment operation cost is distributed repair parts 44%, fuel and lubrication 54% and tires 2%.

Where the overburden is wet, and slurry is required in lieu of ANFO, the labor and equipment operating cost will not change. The supplies costs will be twice that shown on the curves as a result of a increase in the cost of the slurry as compared to ANFO.



SCALE - LOGARITHMIC

5.2.1.3. DRILL AND BLAST OVERBURDEN
OPERATING COST

5.2.1.4. LOAD AND HAUL - OVERBURDEN

The curves show the cost per day for loading and hauling overburden, either common or shot rock, from a pit 90 meters in depth at production rates ranging from 10,000 to 200,000 metric tons per day. One bank cubic meter equals 2.6 metric tons.

The costs for loading and hauling overburden and waste are based on the following criteria:

1. Loading is performed with electric shovels ranging in size from 11 cubic yard capacity to 25 cubic yard capacity.

2. Benches in the pit are 15 meters in height.

3. Hauling is with rear dump trucks ranging in size from 85 ton to 170 ton capacity.

4. Haul roads out of the pit are on a grade of +8% to the pit rim and ± 5% to a dump 4,300 meters one way from the loading unit.

5. Rubber tired wheel dozers and front end loaders are used to maintain the loading area and support the loading operations.

6. Crawler dozers are provided at the dump.

7. A water truck and grader maintain the haul road.

The cost curves reflect an average ratio of 8 trucks per shovel for the required production based on the above criteria. To determine costs for hauls of varying length or depth of pit, multiply the costs obtained from the curves by factors as follows:

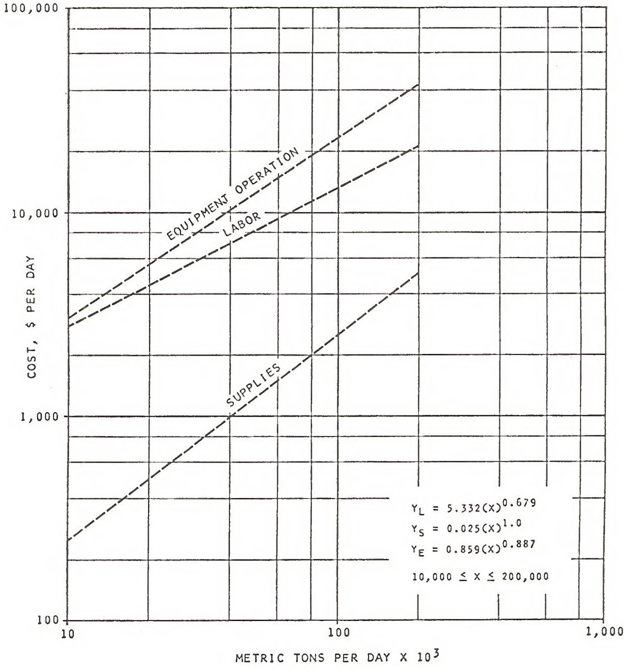
Labor Factor, $F = 0.0967(R)^{0.030}(L)^{0.263}$

Equipment Factor, $F = 0.0422(R)^{0.047}(L)^{0.353}$

Where:
F = Factor
R = Depth of pit in meters (- or 0% grade, r=1.0)
L = Length of haul in meters

Variation in the haul road grade is a function of the depth of pit and length of haul and is incorporated in the curve.

Text continued on page 94.



SCALE - LOGARITHMIC

5.2.1.4. LOAD AND HAUL OVERBURDEN
OPERATING COST

5.2.1.4. LOAD AND HAUL - OVERBURDEN Continued

Labor costs are 70% for operation of equipment and includes pit foreman, shovel operators, oilers, truck drivers, wheel dozer operator, water truck driver, grader oprator and dump dozer operator; and 30% for repair labor to maintain equipment.

Supplies costs are for electric power for shovel operation.

The equipment operating cost is distributed repair parts 24%, fuel and lubrication 36% and tires 40%.

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5.2.2. MINING OIL SHALE

5.2.2.1. DRILL AND BLAST - OIL SHALE

The curves for drilling and blasting oil shale represent the cost for drilling, loading and blasting, plus secondary blasting of 5% of the daily production.

The costs for drilling and blasting are based on the following criteria:

1. The oil shale has a weight of 2.13 metric tons per cubic meter.

2. A powder factor of 0.200 kg per metric ton is required.

3. The oil shale is dry permitting the use of ANFO blasting agent.

4. Drilling is performed using rotary drills and tricone bits. Rotary drills vary in size from 41,000 kg down pressure with 9-7/8" (25.08 cm) bits, to 50,000 kg down pressure with 15" (38.10 cm) bits.

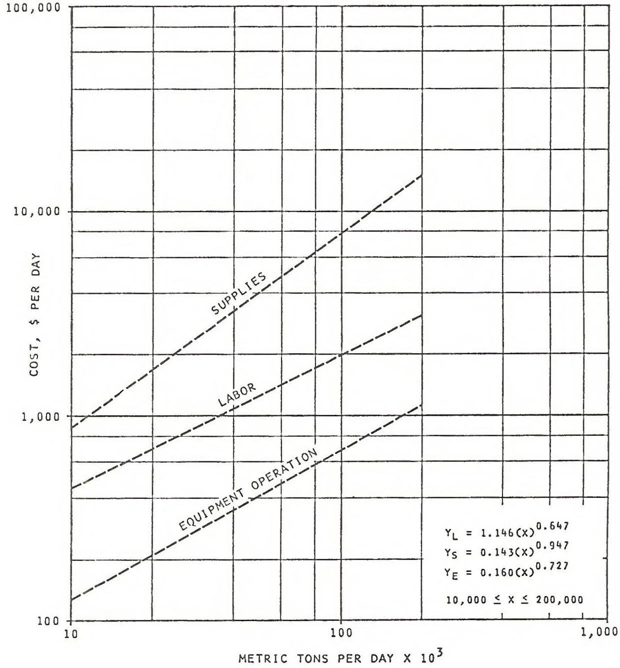
5. Benches are 15 meters high, holes are drilled to a depth of 17.5 meters and are loaded 10.5 meters. Drill patterns vary from 7 meters by 8.5 meters for 9-7/8" (25.08 cm) holes to 10.5 meters by 12 meters for 15" (38.10 cm) diameter holes.

The labor curve includes a drill foreman, drillers and helpers, powdermen and helpers, powder and service truck drivers, plus track driller and chucktender for secondary drilling.

The supplies curve includes rotary bits at 10%, powder and blasting supplies 80% and secondary blasting supplies at 10%.

The equipment operating cost is distributed repair parts 44%, fuel and lubrication 54% and tires 2%.

Where the oil shale is wet, and slurry is required in lieu of ANFO, the labor and equipment operating cost will not change. The supplies costs will be twice that shown on the curves as a result of an increase in the cost of the slurry as compared to ANFO.



SCALE - LOGARITHMIC

5.2.2.1. DRILL AND BLAST OIL SHALE
OPERATING COST

5.2.2.2. LOAD AND HAUL - OIL SHALE

The curves show the cost per day for loading and hauling oil shale from a pit 230 meters in depth at production rates ranging from 10,000 to 200,000 metric tons per day. Oil shale is estimated to have a bank weight of 2.13 metric tons per cubic meter.

The costs for loading and hauling oil shale are based on the following criteria:

1. Loading is performed with electric shovels ranging in size from 11 cubic yard capacity to 25 cubic yard capacity.

2. Benches in the pit are 15 meters in height.

3. Hauling is with rear dump trucks ranging in size from 85 ton to 170 ton capacity.

4. Haul roads out of the pit are on a grade of +8% to the pit rim and then ± 5% to a dump 6,000 meters one way from the loading unit.

5. Rubber tired wheel dozers and a front end loader are used to maintain the loading area and support the loading operations.

6. A water truck and grader will maintain the haul road.

The cost curves reflect an average ratio of 9 trucks per shovel for the required production based on the above criteria. To determine costs for hauls of varying length or depth of pit, multiply the costs obtained from the curves by factors as follows:

Labor Factor, $F = 0.0862(R)^{0.030}(L)^{0.263}$

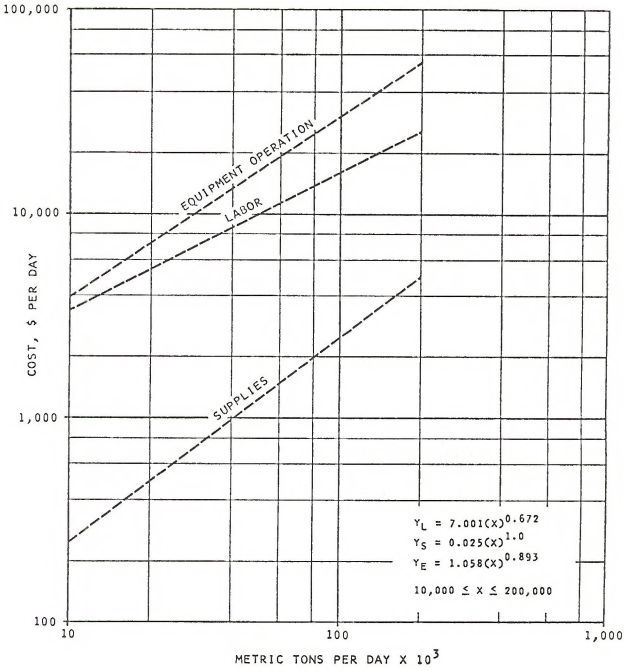
Equipment Factor, $F = 0.0359(R)^{0.047}(L)^{0.353}$

Where:
F = Factor
R = Depth of pit in meters (- or 0% grade, R=1.0)
L = Length of haul in meters

Labor costs are for operation of equipment and includes pit foreman, shovel operators, oilers, truck drivers, wheel dozer operator, water truck driver and grader operator and for repair labor to maintain equipment.

Supplies costs are for electric power for shovel operation.

The equipment operating cost is distributed repair parts 22%, fuel and lubrication 36% and tires 42%.



SCALE - LOGARITHMIC

5.2.2.2. LOAD AND HAUL OIL SHALE
OPERATING COST

5.2.3. GENERAL EXPENSE

General expenses are those costs incurred by the management, technical and administrative operations. Costs are limited to the mine requirements. Home office or other corporate expenses are not included. The costs are determined by selecting the mine rate of production of both oil shale and overburden in tons per day and reading the cost per day from the appropriate curve.

5.2.3.1. ADMINISTRATIVE SALARIES

Administrative salaries are for the management, technical and administrative personnel. Included are the mine manager, engineers, geologists, office group, safety, security and the maintenance and mine top level supervisors. Salaries do not include an allowance for burden. Most administrative personnel are not covered by the same fringe benefits as mine workers and an allowance of 25% will cover burden. However, if they are to be covered the same as mine workers, then use 35%.

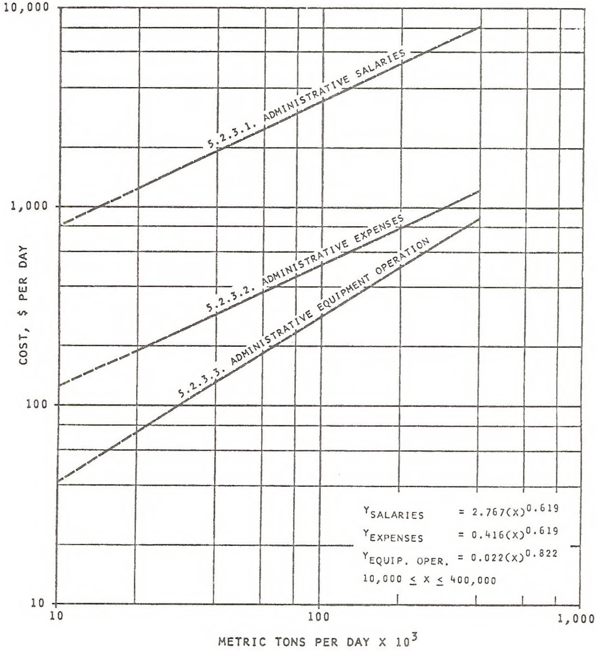
5.2.3.2. ADMINISTRATIVE EXPENSES

Administrative purchases covers office, engineering, safety and first aid supplies and expenses, such as communications, travel, miscellaneous fees, dues, donations, computer services, etc. Also included are small tool allowances.

5.2.3.3. ADMINISTRATIVE EQUIPMENT OPERATION

Administrative equipment consists of sedans, pickup trucks, ambulances, fork lifts, and flat bed trucks used by the administrative personnel.

Administrative equipment operation includes 2% tires, 37% fuel and lube, 21% repair labor and 40% repair parts for the administrative equipment.



SCALE - LOGARITHMIC

5.2.3. GENERAL EXPENSE
OPERATING COST

6. CRUSHING

Crushing is required to reduce the size of the run of mine oil shale to the proper size for retort consumption. The required sizes are as follows:

Method	Maximum Size
Direct Heated	7.6 centimeter
Indirect Heated	7.6 centimeter
Solid Heat	1.3 centimeter
Counter Gravity	5.0 centimeter

The crushing may take place at several locations and no adjustment to the curve values is required for crusher configuration or location. If a Nahcolite recovery circuit is to be included, initial crushing should be to 20.0 centimeters.

Blending of shale feed stocks prior to retorting may be necessary to obtain optimum retorting yields of syncrude. The cost for blending facilities has not been included in the handbook because this operation can be more economically accomplished through selectively mining the shale deposits.

After the shale has been retorted, if either Alumina recovery or slurry disposal is to be used, the product size used to adjust either the capital or operating cost should be 0.2 centimeter.

6.1. CAPITAL COSTS - CRUSHING

Crushing Capital cost is for the acquisition and installation of equipment to crush mine run oil shale to the size required for retort feed. Included in the cost are crushers, conveyors, screens and feeders. Capital cost includes equipment 62%, installation 7%, site preparation 9% and concrete 22%.

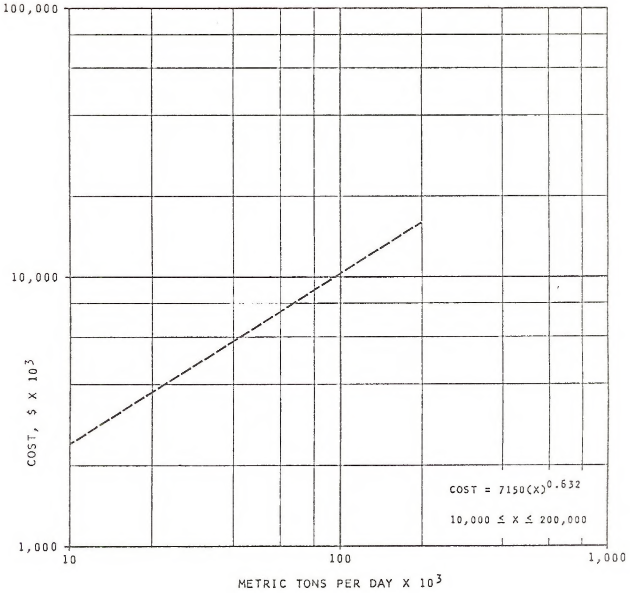
The curve is based on reduction of oil shale from mine run to 1.3 centimeter. Costs for other size requirements may be obtained by multiplying the curve value by the following factor.

$$F = 1.244(P)^{-0.830}$$

Where:
F = Factor to be applied to the cost curve
P = Product size in centimeters

Using the above equation, the following factors may be used for various methods:

Method	Factor
Direct Heated	0.231
Indirect Heated	0.231
Solid Heat	1.000
Counter Gravity	0.327
Nahcolite Recovery	0.104
Alumina Recovery	4.731
Slurry Disposal	4.731



SCALE - LOGARITHMIC

6.1. CRUSHING TO 1.3CM
CAPITAL COST

6.2. OPERATING COSTS - CRUSHING

The crushing costs are for the reduction of the mine run oil shale to the size required for retorting. Included in the curves are all costs associated with crushing, screening, conveying, and transfer of materials, and are valid for multi-stage reduction. The curves are based on reduction of mine run to 1.3 centimeter.

The labor curves include crusher operators, mechanics and general laborers. The labor curve is unaffected by the size reduction, therefore no adjustment to the labor cost is required with variations in product size.

The supplies curve is composed solely of electric power and must be adjusted for variations in product size.

The equipment operation curve covers the operation cost for all crushing plant equipment and includes allowances for the replacement of liners, mantles, bowls, hammers, belts, screens and miscellaneous repair parts. The product size influences the consumption of the equipment parts, therefore the cost must be adjusted.

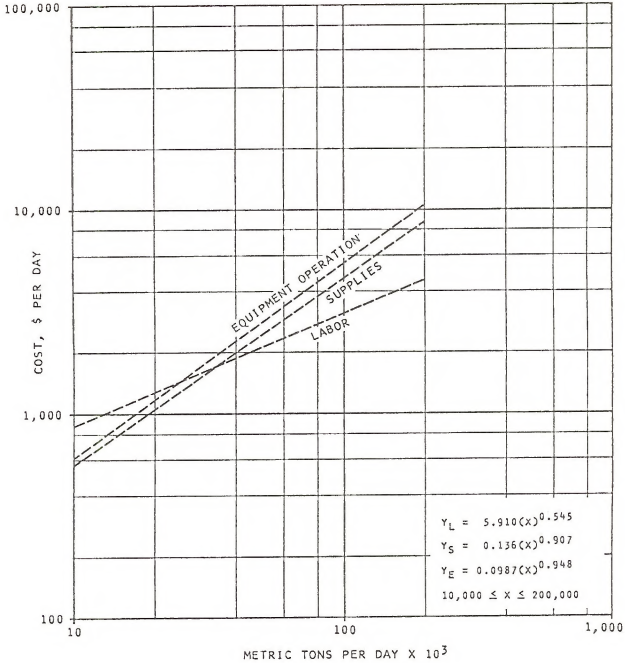
The curve is based on reduction of oil shale from mine run to 1.3 centimeter. Costs for other size requirements may be obtained by multiplying the supplies and equipment operation curve values by the following factor.

$$F = 1.244(P)^{-0.830}$$

Where:
F = Factor to be applied to the costs
P = Product size in centimeters

Using the above equation, the following factors may be used for various methods:

Method	Factor
Direct Heated	0.231
Indirect Heated	0.231
Solid Heat	1.000
Counter Gravity	0.327
Nahcolite Recovery	0.104
Alumina Recovery	4.731
Slurry Disposal	4.731



SCALE - LOGARITHMIC

6.2. CRUSHING TO 1.3CM

OPERATING COST

7. RETORTING AND AUXILIARY PROCESSES

The estimating system for surface retorting provides capital and operating costs for each of the following surface operated processes for extracting kerogens or auxiliary values from the raw oil shale feed stocks.

1. Co-gravity direct heated
2. Co-gravity indirect heated
3. Co-gravity solid heat transfer medium
4. Counter gravity indirect heated
5. Counter gravity indirect heated with steam gas recovery

The handbook also provides for the following associated recovery processes.

1. Nahcolite
2. Alumina

The Nahcolite recovery requires that the raw oil shale be processed prior to retorting and the Alumina recovery be made after the oil shale has been retorted.

Pilot plants capable of processing up to 1,100 metric tons per day with resultant daily yields of as much as 150 cubic meters of syncrude have been built and operated by the developers of these retorting processes.

These developers state that their pilot retorts and operating procedures have been refined to the extent that they can operate "on stream" for long periods of time without major operational difficulties. However, no full scale units have actually been built and put into use by July, 1976.

The following cost data for full scale modules have been developed on the basis of the above experience and typical petroleum process equipment design and construction practice.

The costs developed for shale oil retorting plants employing any given type of retort include provision for a minimum of 20% standby retorting capacity in order to insure continuity of refining operations. The following tables show (1) the productivity of the individual retorting systems in cubic meters of syncrude and (2) the number of active, partly active and standby retorts required for a variety of production levels using a given retorting system.

Capital and operating costs for the individual retorting processes are shown in the following sections. Normally, the cost of a capital or operating item may be determined by calculating the required retorting output in cubic meters and then reading the estimated cost directly from the appropriate curve.

Text continued on page 108.

TABLE 7.a.

INDIVIDUAL RETORT CAPACITIES
Based on Feed Shale Containing 0.146 Cubic Meters Syncrude per Metric Ton *

System	Daily Feed Capacity (Metric Tons)	Syncrude Production (Cubic Meters)	Recovery Fischer Assay
Direct	10,430	1,450	95%
Indirect	10,430	1,450	95%
Solid Heat	9,980	1,460	100%
Counter Gravity	9,080	1,330	100%

* Fischer Assay Value equals 35 gallons per short ton.

TABLE 7.b.

RETORTING UNITS PER DAILY PRODUCTION
Cubic Meters per Day Shale Oil

Process	1,590	3,180	4,770	6,360	7,950	15,900	23,850
Direct or Indirect							
Active Units	1	2	3	4	5	11	17
Part Active	1	1	1	1	1	1	1
Full Standby	0	0	0	1	1	2	2
Total	2	3	4	6	7	14	20
Reserve Capacity*	82%	37%	22%	37%	28%	28%	22%
Solid Heat transfer							
Active Units	1	2	3	4	5	11	16
Part Active	1	1	1	1	1	0	1
Full Standby	0	0	0	1	1	3	3
Total	2	3	4	6	7	14	20
Reserve Capacity	84%	38%	22%	38%	29%	29%	22%
Counter gravity							
Active Units	1	2	3	5	6	12	18
Part Active	1	1	1	1	0	0	0
Full Standby	0	0	1	0	2	3	4
Total	2	3	5	6	8	15	22
Reserve Capacity*	67%	25%	39%	25%	34%	25%	23%

* Expressed as percent of daily production.

In using the curves for shale oil retorting, the user must bear in mind that they are based on a feed stock containing 0.146 cubic meters per metric ton. Because the output of an oil shale retort is largely determined by the tonnage of feed shale which it can process daily, the yield of syncrude is dependent on the kerogen content of the feed shale. Therefore, when processing oil shale having more or less than 0.146 cubic meters per metric ton, it is necessary to adjust the cubic meters per day of syncrude use as input into the appropriate curves by the factor below. This adjusted value is used only to obtain the cost and is not the actual production rate of the retort unit. The actual production is that selected by the user. Use the following factor for oil shale containing other than 0.146 cubic meters of shale oil per metric ton to determine the input value to be used.

F = 0.146/Z

Where:
F = Factor to be used for adjustment
Z = Actual retort feed shale oil content in cubic meters per metric ton

Example:
Z = 0.153 cubic meters per metric ton of shale oil
Syncrude production = 4,770 cubic meters per day

Therefore:
F = 0.146/0.153 = 0.954
Input value = 0.954(4,770) = 4,551 cubic meters per day

Capital and operating costs for each retorting system recognize the number of active, partially active, and standby retorting modules which Table 7.b. indicates are required to support daily syncrude production of between 1,590 and 23,850 cubic meters (10,000 to 150,000 barrels) per day.

In presenting costs for each of the oil shale retorting processes, the retorts themselves are considered to be an integral part of a retorting/upgrading complex which also contains the facilities necessary for supporting this complex. Therefore, in order to estimate the cost of surface retorting, it is necessary to incorporate the cost from Section 9., Upgrading and Section 10., Facilities for Retorting and Upgrading.

The general expense portion of the operating costs covering managerial, technical and administrative support for the entire retorting/upgrading complex is provided under Section 10.2.1.

In order to escalate the capital cost in this section, the cost index shown in Section 2.3., Item 7. may be used. The operating cost may be escalated by using the cost index in Section 2.3., Item 3. or by using the distribution provided in the text.

7.1. CO-GRAVITY DIRECT HEATED

The co-gravity direct heated process represents the latest refinements of the oldest proven device for oil shale extraction, namely, using a vertical shaft retort. A cutaway drawing of the co-gravity direct heated retort is presented in Drawing 7.1.a. and a flow sheet of the entire process is shown in Drawing 7.1.b. Operation of this retort is achieved by the simultaneous movement of shale and gas-air mixture.

Lumps of feed shale, which have been previously crushed to minus 7.6 and plus 1.3 centimeters, are fed into the top of the retort at an inflow rate which is sufficient to offset the withdrawal of spent shale through the adjustable grates at the lower end of the retort. By this balancing of shale flows, the retort is kept uniformly filled.

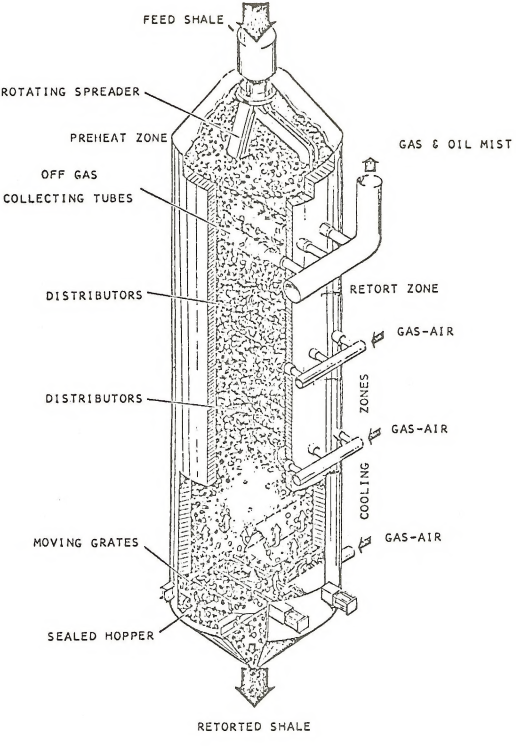
As it moves downward, the shale first passes through the preheating zone located above the off gas collectors. It next goes through the retorting zone and over two levels of gas burner beams (heat distributors). The retorted or spent shale then moves through a cooling zone, across the hydraulically actuated grate and into an airtight hopper. The hopper provides a seal for the retort and also meters the discharge of spent shale.

As the shale flows downward through the retort, a mix of product gas and air is fed into the retort by way of three distributors at the locations shown in Drawing 7.1.a.

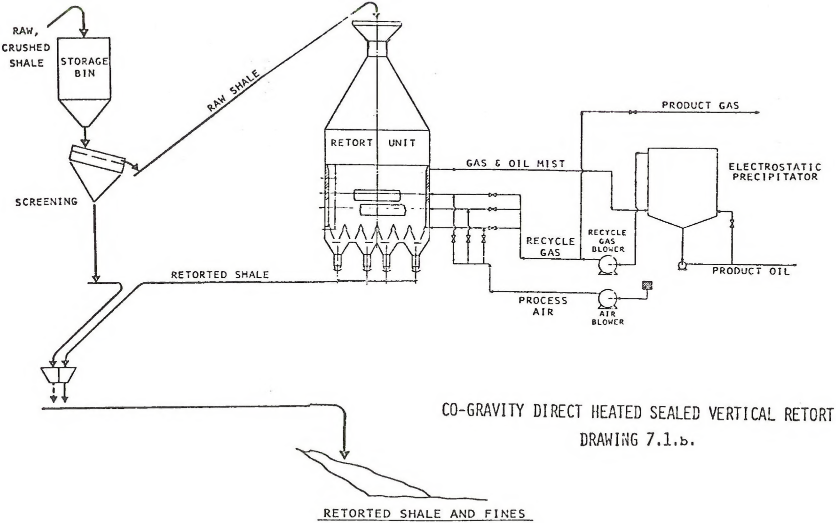
The first distributor is at the grate. Here a cool gas-air mixture moves across the grates and upward to cool the spent shale while becoming preheated. At the other two locations, gas and air is led from the distributors into gas burner beams situated at the lower and mid portions of the retorting zone. Here the heat necessary for retorting is obtained from the ongoing combustion of the gas-air mixtures.

After combustion, the mixture of burnt and unburnt gases and product shale vapors is drawn off by collecting tubes and led to an oil recovery unit for further processing.

The curves for the co-gravity direct heat retorting system are based on oil shale containing 0.146 cubic meter of shale oil per ton. For adjustment of curve input values for other shale oil contents, see Section 7. This system is assumed to recover about 95% of the Fischer assay. The portion of the mine production that is minus 1.3 centimeters is wasted in this retort. This can be assumed at 10% of the mine production.


FEED SHALE
ROTATING SPREADER
PREHEAT ZONE
GAS & OIL MIST
OFF GAS
COLLECTING TUBES
RETORT ZONE
DISTRIBUTORS
GAS-AIR
ZONES
DISTRIBUTORS
GAS-AIR
COOLING
GAS-AIR
MOVING GRATES
SEALED HOPPER
RETORTED SHALE

DETAIL DRAWING OF CO-GRAVITY DIRECT HEATED RETORT
DRAWING 7.1.a.


RAW, CRUSHED SHALE
STORAGE BIN
SCREENING
RAW SHALE
RETORT UNIT
GAS & OIL MIST
PRODUCT GAS
ELECTROSTATIC PRECIPITATOR
RECYCLE GAS
RECYCLE GAS BLOWER
PRODUCT OIL
PROCESS AIR
AIR BLOWER
RETORTED SHALE
RETORTED SHALE AND FINES

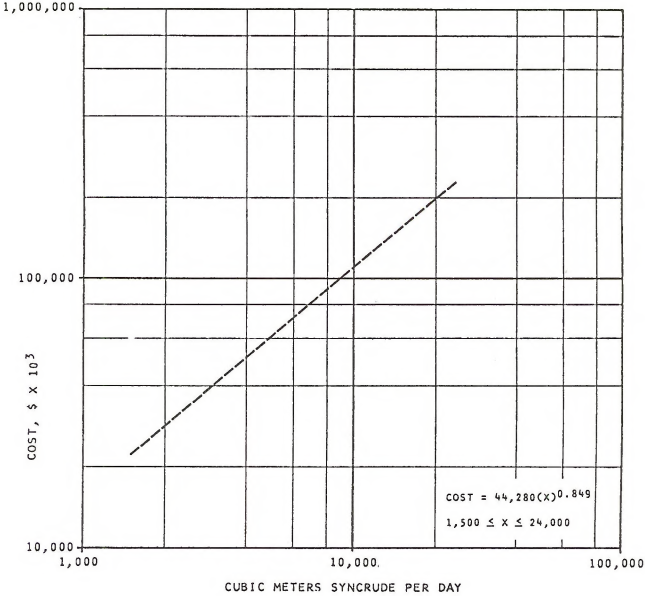
CO-GRAVITY DIRECT HEATED SEALED VERTICAL RETORT

DRAWING 7.1.b.

7.1.1. CAPITAL COSTS - CO-GRAVITY DIRECT HEATED

Capital costs for the co-gravity direct heated retorting system are based on modules of the retorting system schematically shown in Drawing 7.1.b. They include the retort unit assembly, blowers, precipitators and other auxiliaries necessary for its operation.

This capital cost curve contemplates using retorting modules in combinations as shown in Table 7.b.



SCALE - LOGARITHMIC

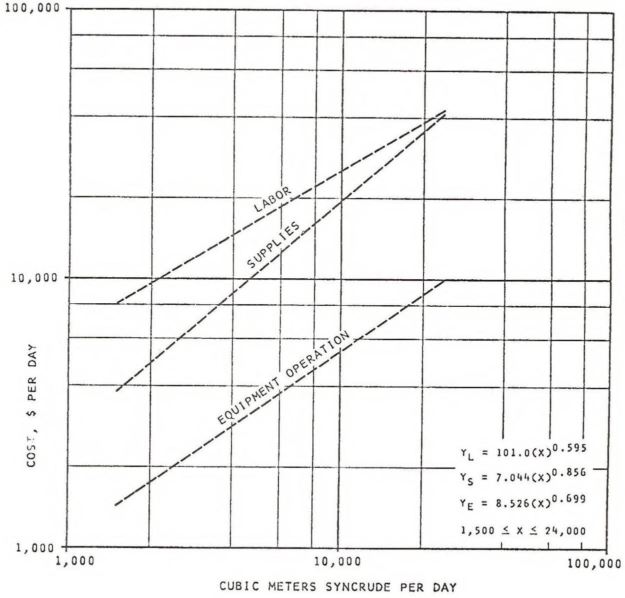
7.1.1. CO-GRAVITY DIRECT HEATED RETORT
CAPITAL COST

7.1.2. OPERATING COSTS - CO-GRAVITY DIRECT HEATED

Plant operating costs for the co-gravity direct heated retorting system is considered to be an element of an entire retorting/upgrading complex, therefore Figure 7.1.2. represents only the retorting system plant operating costs.

Supplies include electric power 75%, water cost 13%, and 12% miscellaneous costs.

Equipment operation costs cover repair parts 90% and lubricants 10%.



SCALE - LOGARITHMIC

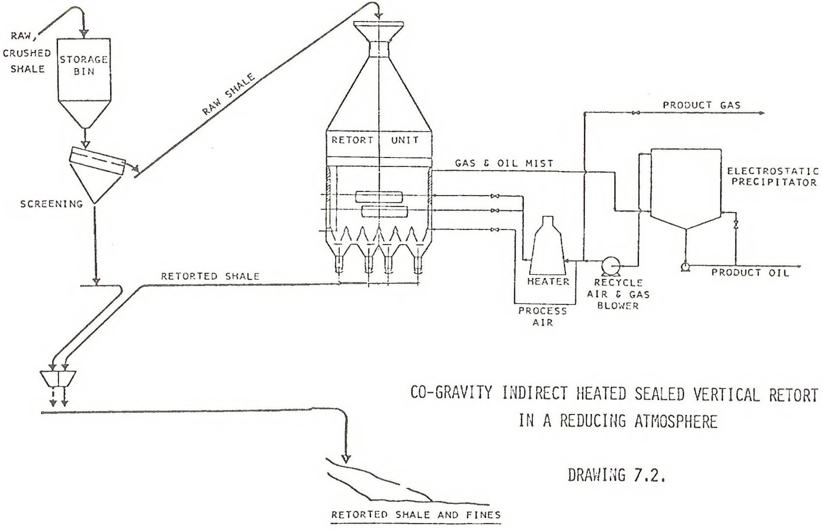
7.1.2. CO-GRAVITY DIRECT HEATED RETORT
OPERATING COST

7.2. CO-GRAVITY INDIRECT HEATED

This process employs a retort and process auxiliaries similar to the ones used in the previously described co-gravity direct heated process. The accompanying flow sheet, Drawing 7.2., shows the principal process elements. A comparison between this and the flow sheet for the direct process, Drawing 7.1., indicates that with the exception of an added heater and closed process air system, the two processes appear to be nearly identical. However in the indirect process, the injection of preheated fuel gas into the pyrolizing zones of the retort replaces direct combustion of the feed shale as the retorting medium.

The temperature profile within the retort is developed and maintained to optimize retorting of the raw shale by regulating the temperature and flow rates of the pre-heated gas at each of the retort's distributors.

The curves for the co-gravity indirect heat retorting system are based on oil shale containing 0.146 cubic meters of shale oil per ton. For adjustment of curve input values for other shale oil contents, see Section 7. This system is assumed to recover about 95% of the Fischer assay. An additional loss is due to the wasting of the fines and can be assumed as 10% of the mine production.


RAW, CRUSHED SHALE
STORAGE BIN
SCREENING
RAW SHALE
RETORT UNIT
GAS & OIL MIST
PRODUCT GAS
ELECTROSTATIC PRECIPITATOR
HEATER
RECYCLE AIR & GAS BLOWER
PROCESS AIR
PRODUCT OIL
RETORTED SHALE
RETORTED SHALE AND FINES

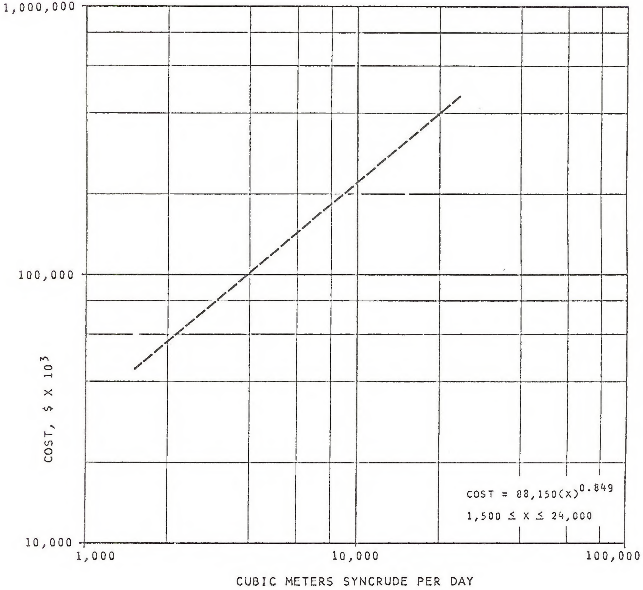
CO-GRAVITY INDIRECT HEATED SEALED VERTICAL RETORT
IN A REDUCING ATMOSPHERE

DRAWING 7.2.

7.2.1. CAPITAL COSTS - CO-GRAVITY INDIRECT HEATED

The co-gravity indirect heated retorting system shown in Drawing 7.2. including a retort similar to the one in Drawing 7.1. is used as the basis for the costs of this system.

The capital costs include the retort and other appurtenances for the co-gravity indirect heated system as well as the gas heater and other related auxiliary equipment items necessary to operate in this mode. They also include the cost of providing for standby retorting capacity as calculated in Table 7.b.



SCALE - LOGARITHMIC

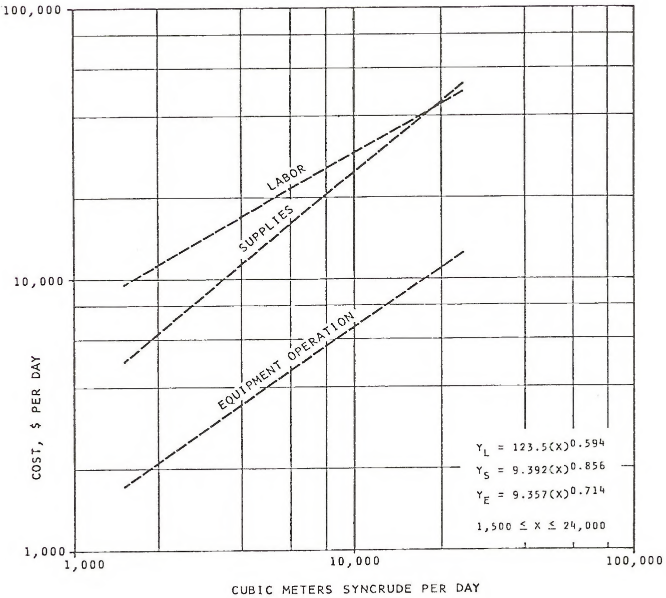
7.2.1. CO-GRAVITY INDIRECT HEATED RETORT
CAPITAL COST

7.2.2. OPERATING COSTS - CO-GRAVITY INDIRECT HEATED

Plant operating costs for the co-gravity indirect heated retorting system are considered to be an entire element of retorting/upgrading complex, therefore Figure 7.2.2. is only for retorting system plant operating costs.

Supplies include electric power 75%, water cost 13%, and miscellaneous cost 12%.

Equipment operation includes repair parts 90% and lubricants 10%.



SCALE - LOGARITHMIC

7.2.2. CO-GRAVITY INDIRECT HEATED RETORT
OPERATING COST

7.3. CO-GRAVITY SOLID HEAT TRANSFER MEDIUM

This retorting process has been developed during the past twenty years. It has been successfully operated in both a 25 ton per day pilot plant and 1,000 ton per day semi-works installation.

The curves for this system are based on oil shale containing 0.146 cubic meters of shale oil per ton. For adjustment of curve input values for other shale oil contents, see Section 7.

The principal characteristics are:

1. Processes the smallest size particles (minus 1.3 cm) of any retorting process. Therefore, this process can operate on fines unacceptable to the other retorts.

2. Employs a solid heat transfer medium (preheated ceramic pellets). This in turn provides a means of controlling the process by regulating the preheating temperature and inflow rates for the pellets.

3. Uses a rotating drum retort resembling units used in cement production, to create an intimate contact between pellets and the finely ground shale and expedite release of kerogens from the feed stock.

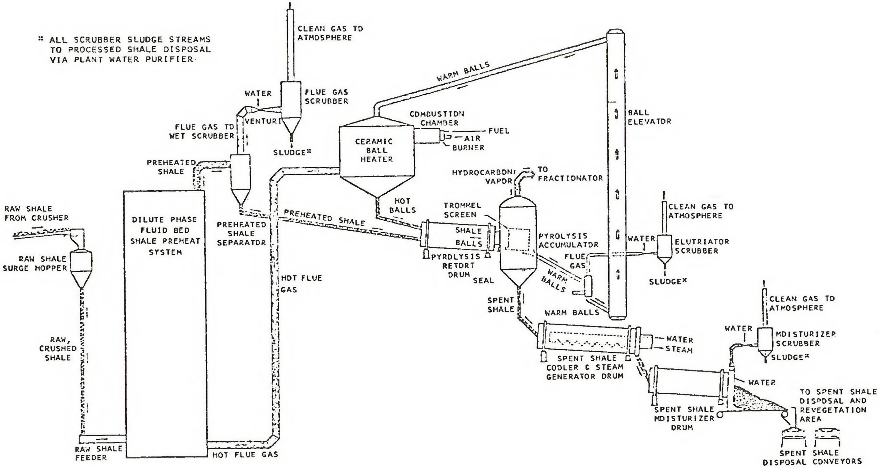
A schematic flow sheet for this process is shown in Drawing 7.3. The process itself comprises the following continuous operations.

Crushed raw shale (minus 1.3 cm) is fed into a "dilute phase fluid bed shale preheat "system". This system utilizes hot flue gas to raise the feed shale temperature to approximately 200°C. The shale is then led along with the flue gas into a separator where it is separated from the dusty flue gas and transported to the co-gravity solid heat retort.

In this retort, the preheated shale is mixed with hot (approximately 650°C), 1.3 centimeter diameter, ceramic balls which are being fed into the retort from the vertical ball heater, further described below.

The solid-to-solid heat exchange, which occurs during the mixing and flow of the shale and ceramic balls, heats the raw shale to a retorting temperature of about 480°C. At this point, kerogens are liberated from the shale matrix and converted into hydrocarbon vapors. Following this release, the mix of vapors, spent shale and ceramic balls flows into the pyrolysis accumulator for separation.

Text continued on page 124.



* ALL SCRUBBER SLUDGE STREAMS TO PROCESSED SHALE DISPOSAL VIA PLANT WATER PURIFIER.

CLEAN GAS TO ATMOSPHERE
WATER
FLUE GAS SCRUBBER
VENTURI
FLUE GAS TO WET SCRUBBER
SLUDGE*
PREHEATED SHALE
RAW SHALE FROM CRUSHER
RAW SHALE SURGE HOPPER
DILUTE PHASE FLUID BED SHALE PREHEAT SYSTEM
PREHEATED SHALE SEPARATOR
PREHEATED SHALE
RAW, CRUSHED SHALE
RAW SHALE FEEDER
HOT FLUE GAS
HOT FLUE GAS
WARM BALLS
CERAMIC BALL HEATER
COMBUSTION CHAMBER
FUEL
AIR
BURNER
HOT BALLS
HYDROCARBON VAPOR
TO FRACTIONATOR
TROMMEL SCREEN
SHALE
BALLS
PYROLYSIS RETORT DRUM
SEAL
PYROLYSIS ACCUMULATOR
FLUE GAS
WARM BALLS
BALL ELEVATOR
CLEAN GAS TO ATMOSPHERE
WATER
ELUTRIATOR SCRUBBER
SLUDGE*
SPENT SHALE
WARM BALLS
WATER
STEAM
SPENT SHALE COOLER & STEAM GENERATOR DRUM
CLEAN GAS TO ATMOSPHERE
WATER
MOISTURIZER SCRUBBER
SLUDGE*
WATER
SPENT SHALE MOISTURIZER DRUM
TO SPENT SHALE DISPOSAL AND REVEGETATION AREA
SPENT SHALE DISPOSAL CONVEYORS

CO-GRAVITY SOLID HEAT TRANSFER MEDIUM RETORT IN A REDUCING ATMOSPHERE

DRAWING 7.3.

Here the hydrocarbon vapors are exhausted into a fractionating column for further upgrading, and the mix of ceramic balls and spent shale are size separated by passage through a rotating screen. The particles of spent shale, being smaller than the ceramic pellets, fall through the screen into a hopper which feeds it into the discharge circuit described below. The larger ceramic pellets flow across the screen and are recycled into the ceramic ball processing system. This processing system then recycles the balls by the following steps:

Residual dust is first removed from the balls by a stream of warm flue gas flowing from the stack of the superheater. Before atmospheric discharge, this flue gas in turn is purged by passage through a venturi type scrubber.

The balls are then returned to the ball heater by means of a vertical bucket elevator. In the ball heater, the balls are reheated to approximately 650°C. At this temperature any residual carbon film is removed from the balls by being converted to flue gas. After this operation, they are then ready to be returned to the pyrolysis operation.

The spent or processed shale is cooled and conditioned for disposal in these two operations:

Step 1.
Spent shale is cooled in a rotating drum steam generator where water sprayed on the hot shale is converted to steam.

Step 2.
The cooled shale's water content is raised to approximately 14 percent in a rotating drum moisturizer. Steam and dusts from process operations are removed by passage through a venturi type scrubber.

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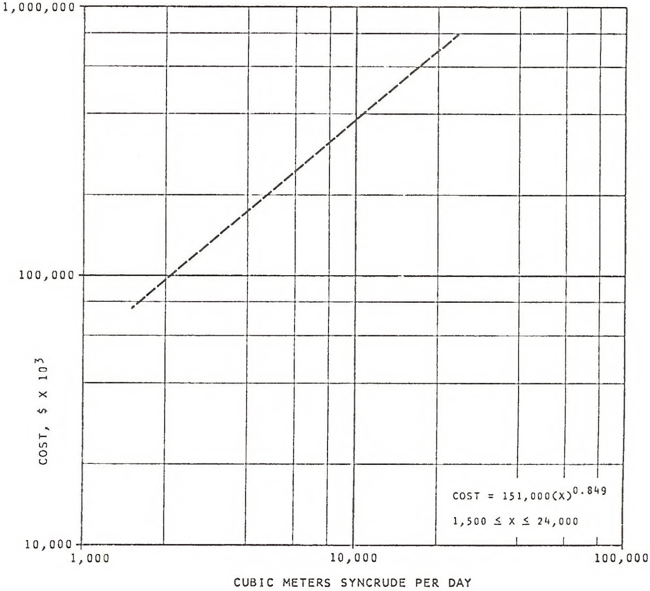
7.3.1. CAPITAL COSTS - CO-GRAVITY SOLID HEAT TRANSFER MEDIUM

Capital costs for the co-gravity solid heat retorting system are based on using modules of the previously described system which is schematically outlined in Drawing 7.3. Processing units contained in the costs include components for the shale preheating system, ceramic ball recycling system, pyrolysis retort drums and accumulators, and the spent shale cooling and moisturizer system.

This capital cost curve contemplates using full scale retorting modules whose individual feed shale capacities are as calculated in Table 7.b.



SCALE - LOGARITHMIC

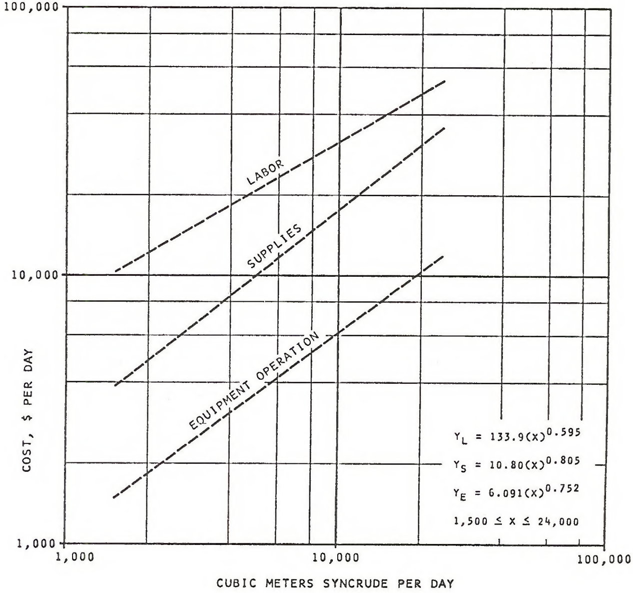
7.3.1. CO-GRAVITY SOLID HEAT TRANSFER MEDIUM RETORT CAPITAL COST

7.3.2. OPERATING COSTS - CO-GRAVITY SOLID HEAT TRANSFER MEDIUM

Operating costs for the co-gravity solid heat transfer medium retorting system are considered part of the retorting/upgrading complex, therefore Figure 7.3.2. covers only the plant operating costs for this retorting system.

Supplies include electric power 80%, water cost 10%, and miscellaneous 10%.

Equipment operation includes repair parts 90% and lubricants 10%.



SCALE - LOGARITHMIC

7.3.2. CO-GRAVITY SOLID HEAT TRANSFER MEDIUM RETORT OPERATING COST

7.4. COUNTER GRAVITY INDIRECT HEATED

This process is a distinct departure from the previously discussed co-gravity or down flow retorts which utilize gravity for moving feed shale through the retorting and cooling zones.

In this retorting system, the concept of counter gravity or up flow retorting has been successfully developed and operated by an oil company whose studies in this field began over 30 years ago.

The up-flow concept has been proved and progressively developed through a series of pilot and demonstration plants starting with a 2 metric ton per day pilot unit and continuing up to a semi-works demonstration retort which handled a peak rate of approximately 1,100 metric tons per day.

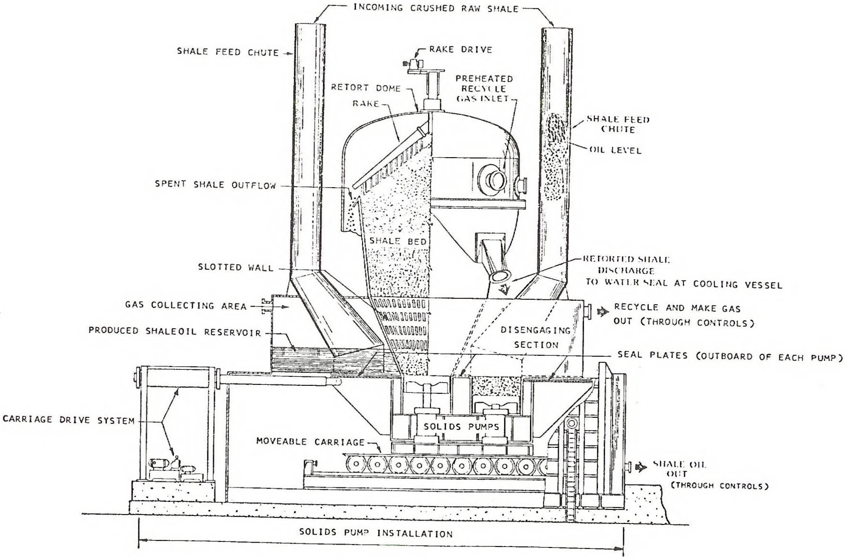
The early retorts employed combustion, (i.e. direct heating), in the retorting zone which used once-through air flow and generated burning temperatures of around 620°C.

Although these units were considered reliable and easy to operate, they were reported to produce yields of syncrude that were only 75% of Fischer assay values, and a product gas of less than 4,470 kilojoules per cubic meter, for which there would be a very limited market.

Therefore, the concept of indirect heating in an upflow retort by supplying a controlled amount of hot flue gas to the retort was developed. This operating mode in turn has proved successful in obtaining yields of syncrude equal to roughly 100% of Fischer assays, and product or make gas with heating values of around 29,800 kilojoules per cubic meter. Drawing 7.4.b. shows the arrangement of the indirect heated retort system including the production, refining and heating of make-up gas for this operation. Additionally, Drawing 7.4.a. presents a cutaway drawing of the retort itself and illustrates many of the unique features discussed in the following description of the process itself.

Raw shale particles crushed to minus 5 centimeters are fed from a feed bin into either of two shale feed chutes. These alternately supply one of the two hydraulically actuated plunger pumps which constitute the working portion of the solids pump assembly. The assembly is mounted on a moveable carriage, and when one of these pumps is positioned beneath its feed chute and receiving raw shale, the other unit discharges its load at the base of the retort to create an upward movement of the entire shale bed. After completion of these operations, the carriage is repositioned and the loading and discharging cycles are repeated.

Text continued on page 132.


INCOMING CRUSHED RAW SHALE
SHALE FEED CHUTE
RAKE DRIVE
RETORT DOME
RAKE
PREHEATED RECYCLE GAS INLET
SHALE FEED CHUTE
OIL LEVEL
SPENT SHALE OUTFLOW
SHALE BED
SLOTTED WALL
RETORTED SHALE DISCHARGE TO WATER SEAL AT COOLING VESSEL
GAS COLLECTING AREA
RECYCLE AND MAKE GAS OUT (THROUGH CONTROLS)
PRODUCED SHALEOIL RESERVOIR
DISENGAGING SECTION
SEAL PLATES (OUTBOARD OF EACH PUMP)
CARRIAGE DRIVE SYSTEM
SOLIDS PUMPS
MOVEABLE CARRIAGE
SHALE OIL OUT (THROUGH CONTROLS)
SOLIDS PUMP INSTALLATION

DETAIL DRAWING OF COUNTER GRAVITY INDIRECT HEATED RETORT

DRAWING 7.4.a.

Seal plates adjacent to each cylinder move with the travel of the carriage to close off the idle feed chute and prevent discharge of shale into the feeder housing.

Meanwhile, fuel gas produced by earlier retorting operations is being scrubbed, compressed, heated to pyrolyzing temperatures from 510°C to 540°C, and injected into the shale at several locations near the top of the retort.

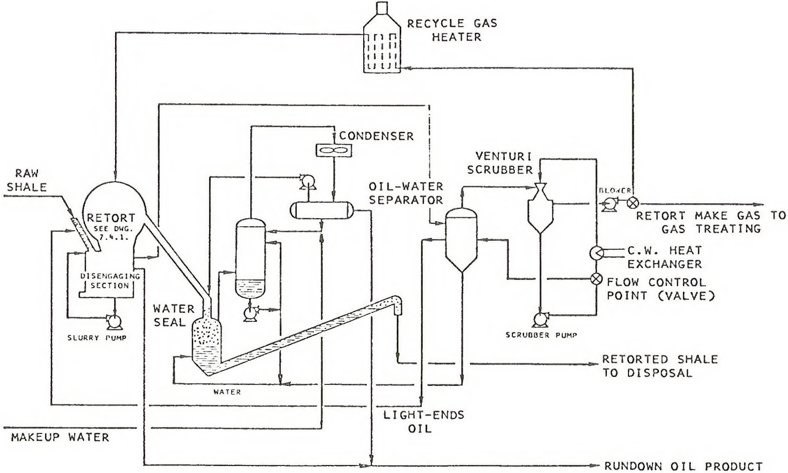
As the shale moves upward, it is pyrolyzed by the downward flow of the hot recycled gas, and releases its kerogens in the form of shale oil, organic gases, and a carbon residue. The hot gas and oil move downward to preheat the incoming shale and eventually separate from the shale in the lower slotted disengaging section surrounding the base of the retort. A carbon residue remains on the surface of the spent shale. The shale product oil passes downward into the lower reservoir and is drawn off for upgrading. Concurrently, the mix of recycle and make gases are discharged from the upper portion of the disengaging section.

After retorting, the spent shale is moved into the free-standing cone at the top of the retort. Here the excess shale is pushed over the retort's lip by a rotating rake, and moves through either of two discharge chutes into a water filled cooling vessel. This vessel both quenches the shale and provides a seal for containment of process gases. After quenching, the cooled shale is moved through the spent shale disposal system via a drag chain conveyor running from the bottom of the quench tank to the top of a spent shale hopper.

In reviewing the operation of this process, it must be noted that this entire retorting system is either valved or sealed by a liquid head of water or shale product oil at all points where entrance or discharge occurs by the following methods:

1. Raw Shale Feed System.
   Feed chutes are filled to a predetermined level with light shale product oil drawn from the reservoir in the disengaging section. This flow is picked up in the piston pumps and recycles back to the reservoir via the slotted wall section in the lower portion of the retort. The cooler oil on the shale surface also acts as a medium for collecting freshly produced shale oil vapors.

2. Processed Shale Discharge System.
   Retort pressure is maintained by closed shale discharge lines leading into a water-filled processed shale moisturizer-cooler. Here the water level is maintained at a specified elevation to act as both a water seal and pressure regulator.


RECYCLE GAS HEATER
CONDENSER
VENTURI SCRUBBER
OIL-WATER SEPARATOR
BLOWER
RETORT MAKE GAS TO GAS TREATING
RAW SHALE
RETORT SEE DWG. 7.4.1.
DISENGAGING SECTION
SLURRY PUMP
WATER SEAL
C.W. HEAT EXCHANGER
FLOW CONTROL POINT (VALVE)
SCRUBBER PUMP
RETORTED SHALE TO DISPOSAL
WATER
LIGHT-ENDS OIL
MAKEUP WATER
RUNDOWN OIL PRODUCT

COUNTER GRAVITY INDIRECT HEATED RETORT
IN A REDUCING ATMOSPHERE

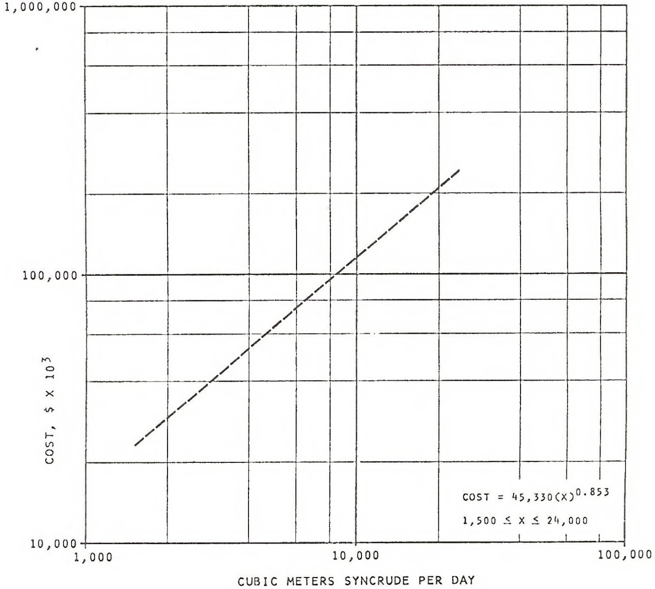
DRAWING 7.4.b.

7.4.1. CAPITAL COSTS - COUNTER GRAVITY INDIRECT HEATED

The counter gravity indirect heated retorting system shown in Drawing 7.4.b. with a retort similar to the one in Drawing 7.4.a. is used as the basis for the capital costs of this system.

These costs include furnishing and installing such features as the feed chutes, solids pumps, hooded vertical retorting unit, spent shale processing lines (including discharge chutes, shale cooling vessel, drag chain conveyor, oil and water separators and cooling water supply system) plus the retort and recycle gas processing installations.

The capital cost curve contemplates using full scale retorting modules whose individual feed shale capacities are as calculated in Table 7.b.



SCALE - LOGARITHMIC

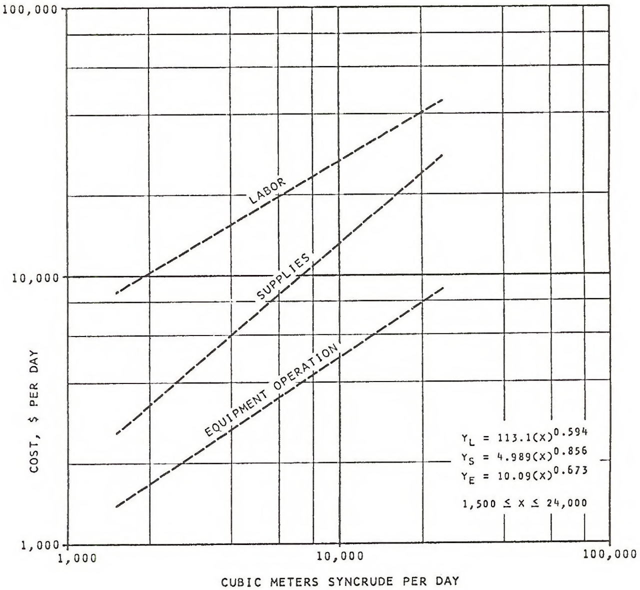
7.4.1. COUNTER GRAVITY INDIRECT HEATED RETORT CAPITAL COST

7.4.2. OPERATING COSTS - COUNTER GRAVITY INDIRECT HEATED

Operating cost for the counter gravity indirect heated retort system are considered part of the retorting/upgrading complex and therefore, Figure 7.4.2. covers only plant operating costs for this retorting system.

Supplies include electric power 76%, water cost 12% and miscellaneous 12%.

Equipment operation includes repair parts 90% and lubrication 10%.



$Y_L = 113.1(X)^{0.594}$

$Y_S = 4.989(X)^{0.856}$

$Y_E = 10.09(X)^{0.673}$

$1,500 \leq X \leq 24,000$

SCALE - LOGARITHMIC

7.4.2. COUNTER GRAVITY INDIRECT HEATED RETORT
OPERATING COST

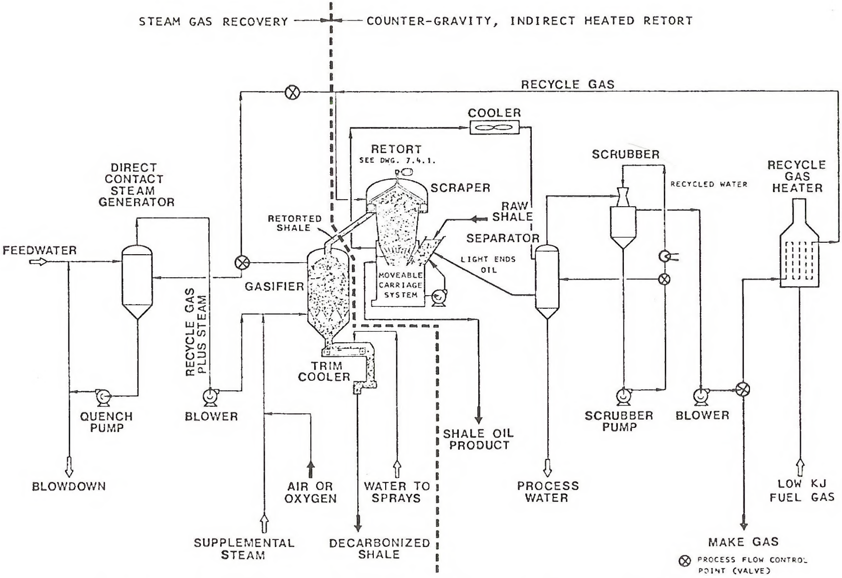
7.5. COUNTER GRAVITY INDIRECT HEATED STEAM GAS RECOVERY

The counter gravity indirect heated steam gas recovery (SGR) system is basically the previously described counter gravity indirect heated retort with an auxiliary process for recovering additional fuel values from the carbon residue on spent shale after being processed in the counter gravity retort.

The difference between these two systems can be seen by comparing the flow sheet, Drawing 7.4.b., for the counter gravity indirect heated process with the flow sheet, Drawing 7.5., for the counter gravity indirect heated steam gas recovery system. The latter drawing shows that instead of being given a water quench for subsequent off site disposal, the hot shale, with its carbon residue, flows directly from the retort into a separate gasifier vessel for further processing.

More than 95% of the residual carbon on the spent shale is removed by a reaction with a mixture of steam and air (atmospheric oxygen) or steam and oxygen to yield hydrogen and steam gas. The hydrogen can be used to upgrade the shale product oil, and the process gas can be used for fueling the direct contact steam generator, or mixed with the recycle gas and injected into the retort.

The heating value of the steam gas itself ranges from 3,700 kilojoules per cubic meter, using a steam-air mixture to 11,000 or more kilojoules per cubic meter with steam-oxygen mixture.


STEAM GAS RECOVERY
COUNTER-GRAVITY, INDIRECT HEATED RETORT
RECYCLE GAS
COOLER
RETORT
SEE DWG. 7.4.1.
SCRAPER
SCRUBBER
RECYCLED WATER
RECYCLE GAS HEATER
DIRECT CONTACT STEAM GENERATOR
RETORTED SHALE
RAW SHALE
SEPARATOR
FEEDWATER
LIGHT ENDS OIL
MOVEABLE CARRIAGE SYSTEM
GASIFIER
RECYCLE GAS PLUS STEAM
TRIM COOLER
QUENCH PUMP
BLOWER
SCRUBBER PUMP
BLOWER
SHALE OIL PRODUCT
BLOWDOWN
AIR OR OXYGEN
WATER TO SPRAYS
PROCESS WATER
LOW KJ FUEL GAS
SUPPLEMENTAL STEAM
DECARBONIZED SHALE
MAKE GAS
⊗ PROCESS FLOW CONTROL POINT (VALVE)

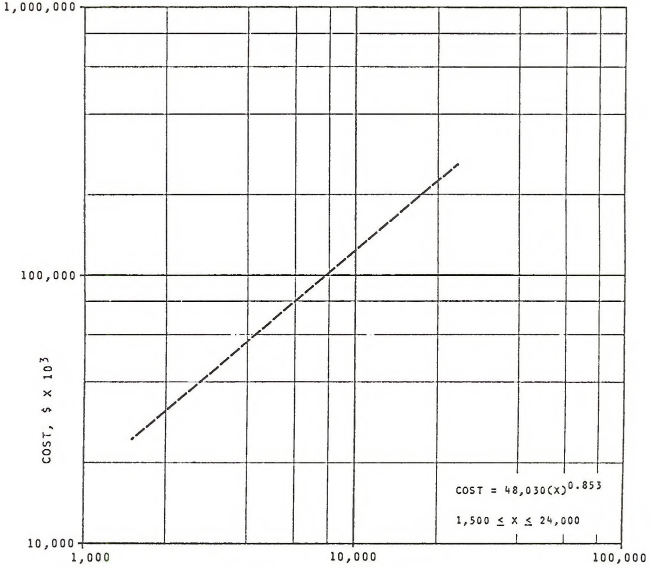
COMBINATION OF COUNTER GRAVITY INDIRECT HEATED RETORT AND STEAM GAS RECOVERY

DRAWING 7.5.

7.5.1. CAPITAL COSTS - COUNTER GRAVITY INDIRECT HEATED STEAM GAS RECOVERY

Drawing 7.5. for the counter gravity indirect heated steam gas recovery system is the basis for capital costs.

These costs include furnishing and installing all of the pertinent items noted in the capital cost for the previously described counter gravity indirect heated retorting system, except the shale cooling vessel and drag chain conveyor which have been replaced by the gasifier vessel and trim cooler. In addition, allowances have been made for the related auxiliary steam generator, air and oxygen supply units as well as the anticipated requirements for the related transfer equipment including piping, pumps, blowers and controls. The above costs also include providing full scale retorting modules as shown in Table 7.b.



SCALE - LOGARITHMIC

7.5.1. COUNTER GRAVITY INDIRECT HEATED RETORT
WITH STEAM GAS RECOVERY SYSTEM

CAPITAL COST

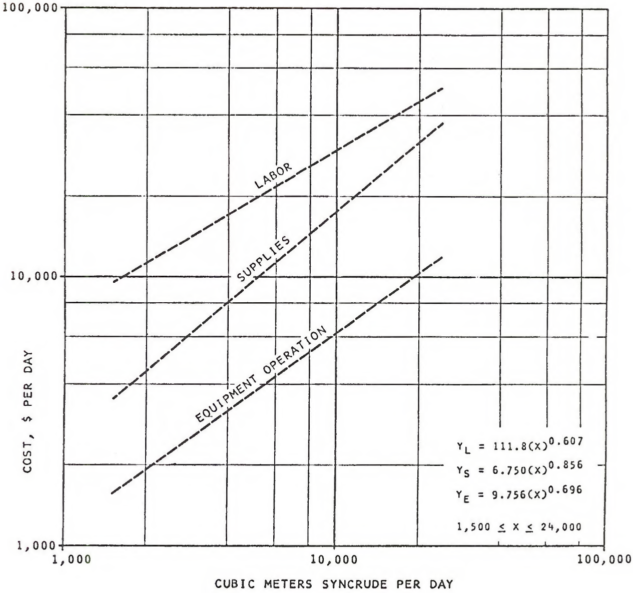
7.5.2. OPERATING COSTS - COUNTER GRAVITY INDIRECT HEATED STEAM GAS RECOVERY

Plant operating costs for the counter gravity indirect heated steam gas recovery system are based on Drawing 7.5.

Provision for management, technical, and administrative services for the retorting systems have been included with the general expense costs presented for the entire retorting/upgrading plant of which the retorting system is an integral part. These general expenses are discussed and presented in Section 10.2.1. Consequently, Figure 7.5.2. covers only the plant operating costs for this retorting system.

Supplies include electric power 74%, water cost 13% and miscellaneous 13%.

The equipment cost curve include repair parts 90% and lubrication 10%.



SCALE - LOGARITHMIC

7.5.2. COUNTER GRAVITY INDIRECT HEATED RETORT
WITH STEAM GAS RECOVERY SYSTEM

OPERATING COST

7.6. NAHCOLITE RECOVERY

Nahcolite occurs with oil shale in certain areas of the Green River formation in sufficient concentrations to make recovery of the mineral an economic possibility. The method of separating the Nahcolite from the other materials is based on the following characteristics.

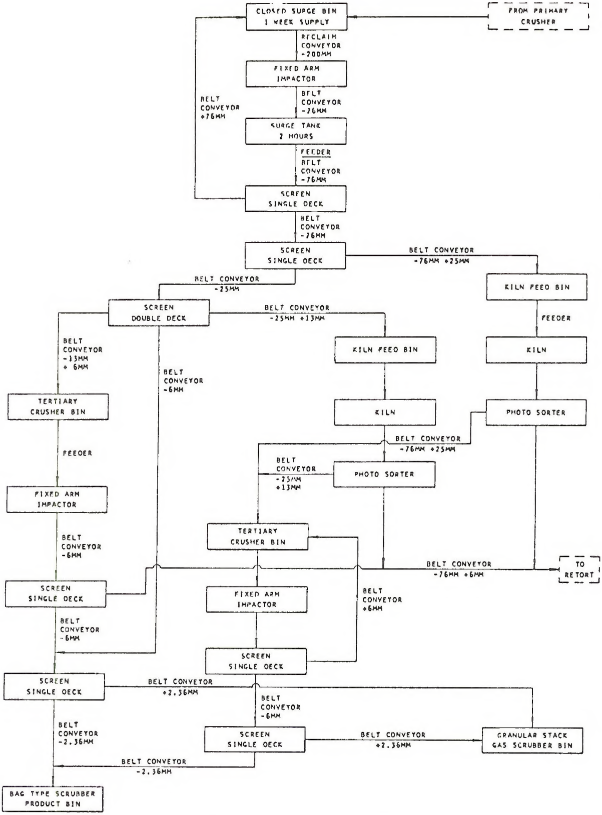
1. Nahcolite is more friable than the accompanying shale, and tends to concentrate in the fines during comminution.

2. Nahcolite when surficially heated becomes coated with white sodium carbonate which contrasts with the dark shale. This contrast in color permits separation in an optical sorting machine.

The capital and operating costs curves are based on 100% of the mined raw oil shale as input into the system. The oil shale is considered to contain 20% Nahcolite with a recovery rate of 80%. The capital and operating costs of Nahcolite recovery are considered to be unaffected by the Nahcolite content of the oil shale. While this is not an exactly valid assumption, the overall cost difference will be within the estimating limits of the handbook. The Nahcolite product should, however, be adjusted to reflect 80% recovery rate of the Nahcolite.

An oil shale retort with upgrading plant and support facilities for retorting and upgrading are considered to be the minimum plant complex required. The addition of a Nahcolite recovery system and/or Alumina recovery system are not considered to add any cost to the retorting, upgrading or support facilities requirements in providing a multi-mineral treatment complex.

For an example of Nahcolite recovery feed and product, see Section 4.

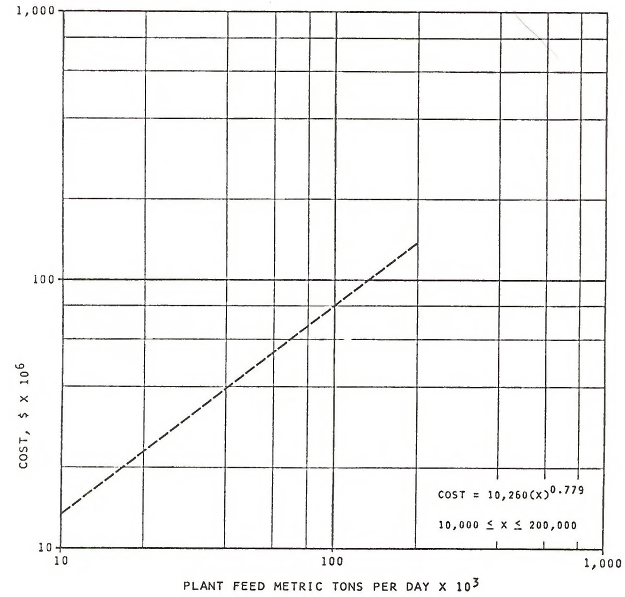

CLOSED SURGE BIN
1 WEEK SUPPLY
FROM PRIMARY CRUSHER
RECLAIM CONVEYOR -200MM
FIXED ARM IMPACTOR
BELT CONVEYOR +76MM
BELT CONVEYOR -76MM
SURGE TANK
2 HOURS
FEEDER
BELT CONVEYOR -76MM
SCREEN
SINGLE DECK
BELT CONVEYOR -76MM
SCREEN
SINGLE DECK
BELT CONVEYOR
-76MM +25MM
KILN FEED BIN
BELT CONVEYOR
-25MM
SCREEN
DOUBLE DECK
BELT CONVEYOR
-25MM +13MM
FEEDER
BELT CONVEYOR -13MM + 6MM
KILN FEED BIN
KILN
BELT CONVEYOR -6MM
TERTIARY CRUSHER BIN
KILN
PHOTO SORTER
BELT CONVEYOR
-76MM +25MM
FEEDER
BELT CONVEYOR -25MM +13MM
PHOTO SORTER
FIXED ARM IMPACTOR
TERTIARY CRUSHER BIN
BELT CONVEYOR -6MM
BELT CONVEYOR
-76MM +6MM
TO RETORT
SCREEN
SINGLE DECK
FIXED ARM IMPACTOR
BELT CONVEYOR +6MM
BELT CONVEYOR -6MM
SCREEN
SINGLE DECK
SCREEN
SINGLE DECK
BELT CONVEYOR
+2.36MM
BELT CONVEYOR -6MM
BELT CONVEYOR -2.36MM
SCREEN
SINGLE DECK
BELT CONVEYOR
+2.36MM
GRANULAR STACK
GAS SCRUBBER BIN
BELT CONVEYOR
-2.36MM
BAG TYPE SCRUBBER
PRODUCT BIN

NAHCOLITE BENEFICIATION

DRAWING 7.6.

7.6.1. CAPITAL COST - NAHCOLITE RECOVERY

The capital costs for Nahcolite recovery are based on the equipment indicated in Drawing 7.6. Costs are for the complete plant. Buildings, foundations, transfer belt to the retort and instrumentation are included. The major plant items are an enclosed surge pile of one week capacity, impact crushers, screens, conveyors, tertiary impact crushers, rotating kilns and photo sort machines. The primary crushing and delivery to the surge bin are included in Section 6.1., Capital Cost - Crushing.



SCALE - LOGARITHMIC

7.6.1. NAHCOLITE RECOVERY
CAPITAL COST

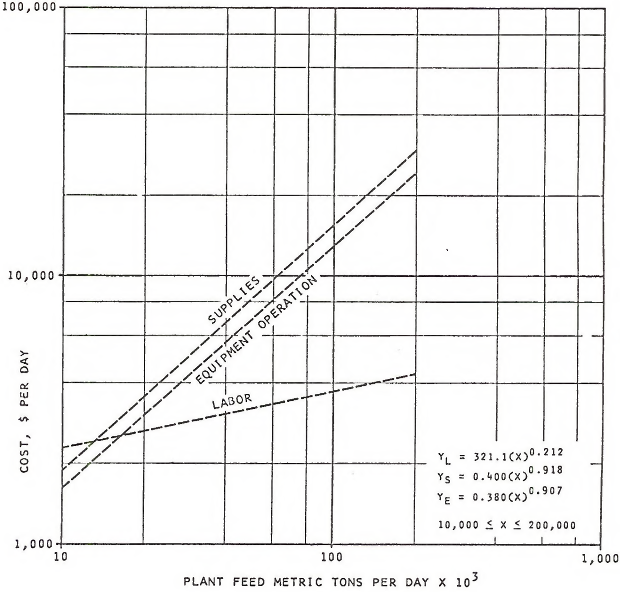
7.6.2. OPERATING COST - NAHCOLITE RECOVERY

The Nahcolite recovery plant is considered to be a part of a multi-mineral treatment complex. The costs of administration would be jointly borne by the various processes. An allowance for the impact of the administrative labor, supplies and equipment operations costs are included as part of the operating costs.

The labor cost includes direct operating, repair and administrative labor.

The supplies curve consists of the electric power consumed in the plant operation.

The equipment operation consists of 94% repair parts and 6% lubrication.



SCALE - LOGARITHMIC

7.6.2. NAHCOLITE RECOVERY
OPERATING COST

7.7. ALUMINA RECOVERY

Dawsonite, an aluminum mineral, occurs with oil shale in certain areas of the Green River formation. Dawsonite contains 35% by weight Alumina and the recovery rate is 73%.

No commercial extraction method for producing Alumina from Dawsonite has been demonstrated. The capital and operating costs presented on these curves are based on published literature of theoretical systems, confirmed in part by bench scale tests. The system, in brief, consists of crushing (Section 6.) the spent shale to minus 0.2 cm with hammermills, leaching in a weak caustic solution, desilicating, carbonating, and calcining to obtain Alumina.

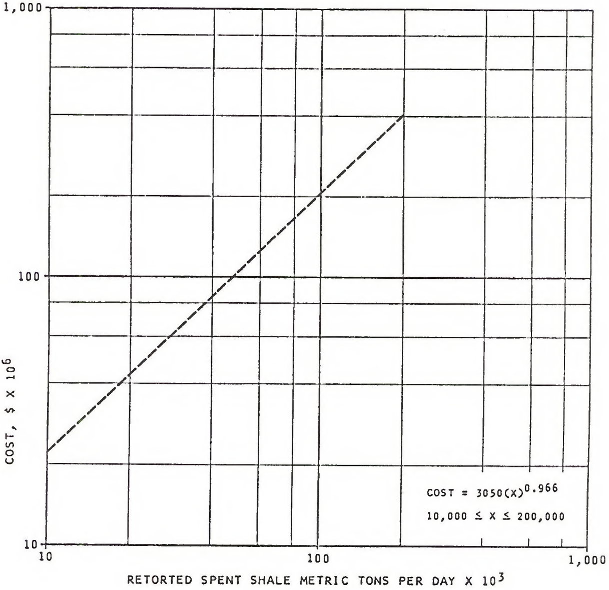
The Alumina recovery unit operates on the spent shale from a retorting operation. It must always be considered as part of a complex and not an independent unit. The initial reaction essential to the Alumina recovery process occurs in the oil shale retort. The Alumina, present in the raw shale as Dawsonite is converted to sodium aluminate during retorting. It is in this form that the leaching may proceed effectively.

The capital and operating cost curve is based on the metric tons per day of spent shale received from the retort complex. This will not equal the mine production as the spent shale tonnage does not include any kerogen removed or in the case of a Nahcolite recovery plant, the material that is removed by that process.

For example of Alumina recovery and waste disposal material, see Section 4.

7.7.1. CAPITAL COST - ALUMINA RECOVERY

The capital cost consists of the equipment, structures, foundations, piping and instrumentation required to process the Dawsonite rich spent shale. The equipment includes a belt conveyor from the retort spent shale discharge point to hoppers feeding the hammermills, leach tanks, thickeners, agitator tanks, filters, rotary kilns, belt conveyors and pumps. The underflow from the thickeners is pumped to a tailings disposal point as a 50% solids slurry.



SCALE - LOGARITHMIC

7.7.1. ALUMINA RECOVERY
CAPITAL COST

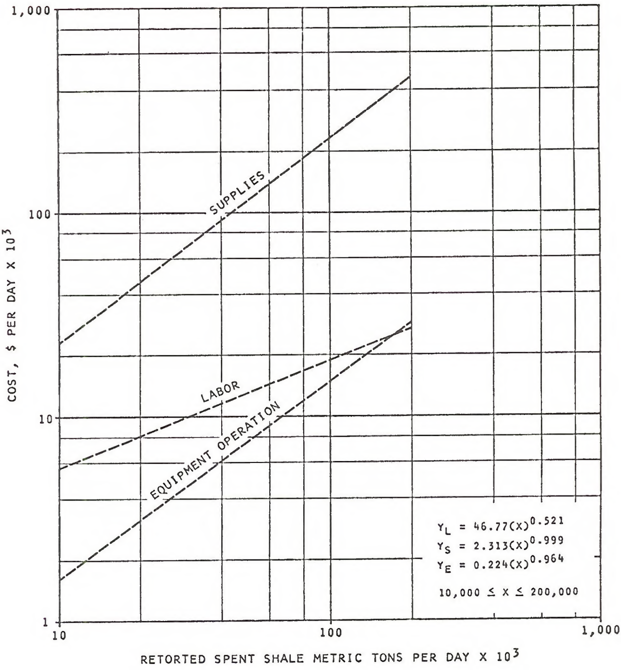
7.7.2. OPERATING COST - ALUMINA RECOVERY

The operating costs are those directly attributable to the Alumina recovery process. The labor costs include a foreman for each operational unit, but do not include a plant manager, engineering, safety, accounting or other administrative costs. The Alumina recovery can only be operated as an adjunct to an oil shale retorting process. The administrative operating costs are treated as a part of the retorting/upgrading complex administrative costs.

The labor curve includes operators for the equipment and repair labor for equipment maintenance.

The supplies costs consists of 10% for electric power and 90% for lime.

The equipment operation includes 93% repair parts and 7%. lubrication.



SCALE - LOGARITHMIC

7.7.2. ALUMINA RECOVERY
OPERATING COST

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8. MODIFIED IN SITU RETORTING

Modified in situ retorting does not have a history of commercial production; therefore, the cost curves in this section are based on the most promising systems appearing in the published literature. The systems are designated as "A" and "B" on the curves. The following basic assumptions are applicable to both systems:

1. Kerogen recovery = 60%
2. Shale oil content = .10 cubic meters/metric ton
3. Required void area = 20%
4. Retort burn rate = 50 mm/hr

Items 1., 3. and 4. are constant in this estimating system. Item 2. may be adjusted for oil shale deposits containing a different average shale oil content in the following manner.

CCMPD = CMPD(0.100/SOC)

Where:
CMPD = Cubic meters per day of desired production
SOC = Shale oil content in cubic meters per metric ton
CCMPD = Curve mine production in cubic meters per day

The data used to develop the cost curves on modified in situ retorting which was available at the time of this study (July, 1976) was very limited. Currently, in situ schemes are being proposed for lease tracts C-a and C-b and these developments occurred after the data for the study had been accumulated.

Costs for both systems are based on a retort height of 150 meters with factors provided for adjustments to different heights. The nominal retort size range is considered to be from 60 meters to 150 meters in height.

It will be noted that as the retort height decreases from the 150 meter base case, the cost of syncrude increases. The reason for this becomes apparent with a study of the geometry of the modified in situ schemes. The upper access level, lower access level and off gas level require essentially the same effort regardless of the height of retort. The amount of syncrude produced from a retort decreases directly as the height is decreased (assuming the cross section is constant) thus causing the cost of syncrude to rise as less syncrude is produced from the shorter retort to pay for the same amount of retort preparation work. The rubblization effort will vary directly as the height of the retort and will therefore not affect the cost trend.

No adjustment is made for variable horizontal cross section of the retort. It is assumed that the optimum cross section is used in developing the costs for syncrude production and the adjustment is reflected in the correction factor for varying retort heights.

No breakdown of cost components is made in this section. Escalation must be accomplished with a composite index representative of the operations considered.

SCHEME "A"

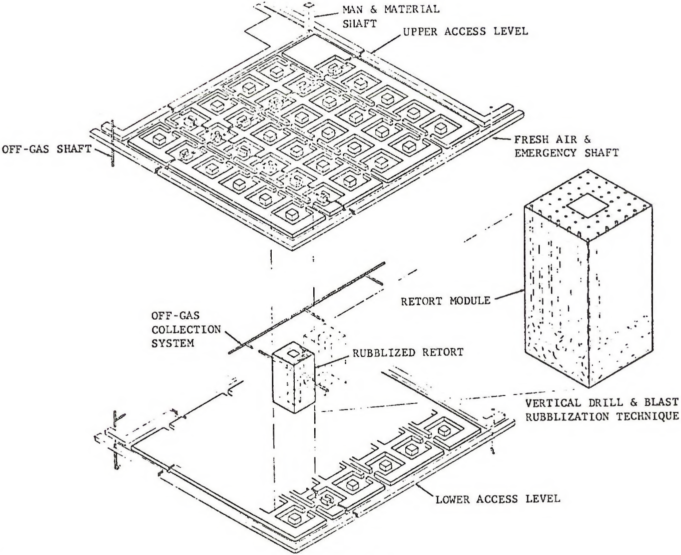
Scheme "A" is a system based on drill and blast type development work and rubblization. The retorts are developed by mining an expansion chamber at the bottom and a drill station at the top of the retort. The retorts vary in size from 37 by 37 meters to 55 by 55 meters in section. The rubblization is accomplished by drilling vertical holes from the top drill station through the retort and then blasting. The retort is ignited at the top and the kerogen is removed from the bottom and pumped to the surface. Drawing 8.a. illustrates the scheme. The modified in situ system produces a significant amount of broken shale that must be taken to the surface and disposed of by dumping or by a surface retort. The following formula may be used to determine this amount on a daily basis for Scheme "A":

$$Y = 764.7(H)^{-1.084}(X)$$

Where:

Y = Metric tons per day of oil shale to the surface
H = Height of retort
X = Production rate in cubic meters per day of shale oil

Text continued on page 158.


MAN & MATERIAL SHAFT
UPPER ACCESS LEVEL
OFF-GAS SHAFT
FRESH AIR & EMERGENCY SHAFT
RETORT MODULE
OFF-GAS COLLECTION SYSTEM
RUBBLIZED RETORT
VERTICAL DRILL & BLAST RUBBLIZATION TECHNIQUE
LOWER ACCESS LEVEL

SCHEME 'A'
EXPLODED ISOMETRIC VIEW - ROOM AND PILLAR MINING SYSTEM
DRAWING 8.a.

8. MODIFIED IN SITU RETORTING Continued

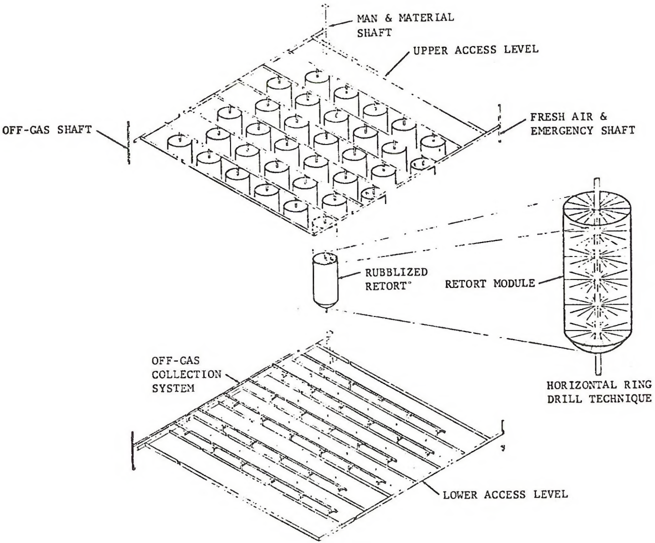
SCHEME "B"

Scheme "B" is a system based on mechanical boring machines for both access tunnel development and raise development. The retorts are developed by driving parallel access tunnels with tunnel boring machines at both the lower and upper access levels. These levels are connected by raises driven with raise boring machines. The retort is then drilled with a horizontal ring pattern from the raise and rubblized by blasting. The raise supplies the expansion void in this instance. The retorts are circular in section and vary from 10 meters to 30 meters in diameter. The retort is ignited at the top and the kerogen is removed from the bottom and pumped to the surface. Drawing 8.b. illustrates the scheme. The modified in situ system produces a significant amount of broken shale that must be taken to the surface for disposal by dumping or through a surface retort. The following formula may be used to determine this amount on a daily basis for Scheme "B":

$$Y = 90.21(H)^{-0.624}(X)$$

Where:

Y = Metric tons per day of oil shale to the surface
H = Height of retort
X = Production rate in cubic meters per day of shale oil


MAN & MATERIAL SHAFT
UPPER ACCESS LEVEL
OFF-GAS SHAFT
FRESH AIR & EMERGENCY SHAFT
RUBBLIZED RETORT
RETORT MODULE
HORIZONTAL RING DRILL TECHNIQUE
OFF-GAS COLLECTION SYSTEM
LOWER ACCESS LEVEL

SCHEME 'B'
EXPLODED ISOMETRIC VIEW - TUNNEL BORING MINING SYSTEM
DRAWING 8.b.

8.1. CAPITAL COSTS

The capital costs for the in situ retorting process are those costs involved in developing the property to the extent the desired production rate may be sustained. Included is sinking men and material shafts, fresh air shafts and off-gas shafts. Development of the main access level, upper access level and off-gas level are carried out to the extent that a continuing development program will result in the availability of retorts at the same rate that the retorts are consumed. Capital costs include the cost of placing the required number of retorts in operation to sustain the desired production rate. In addition, rubblization of further retorts must be completed to the extent that a constant labor force and equipment spread will supply new retorts for oil shale production at the same rate as the producers are exhausted.

8.1.1. MINE DEVELOPMENT

Mine development costs are the costs incurred in developing the access levels, off-gas level, and placing the retorts in production. The costs do not include shafts and pump installation or the cost of the mine and retort equipment. The mine development costs are significantly affected by the height of the retort. A similar amount of access and off-gas tunneling is required in any retort operation independent of the height. The curves are based on a retort height of 150 meters with a factor for adjustment to other retort heights.

To obtain the cost of mine development, select the scheme of retort construction desired, "A" or "B". Adjust for difference in the shale oil content and enter the curve at the selected mine production in cubic meters per day of shale oil. After determining the cost for the scheme at 150 meters retort height, an adjustment to this cost may be made for a retort height other than 150 meters by using the following factors:

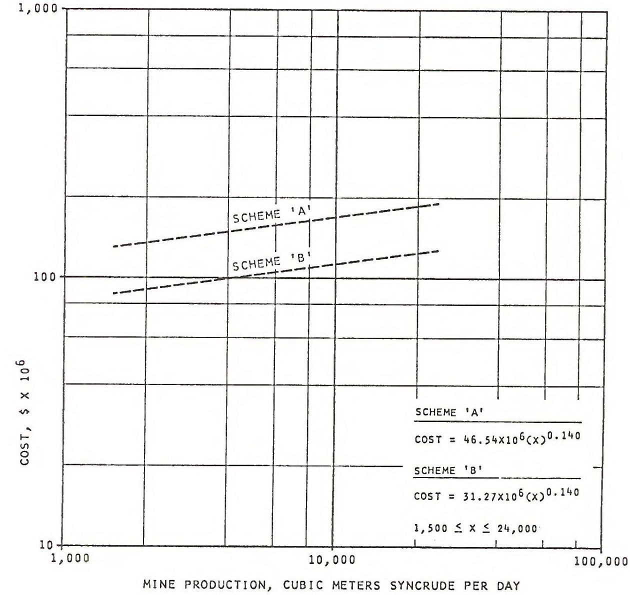
For mine development scheme "A":

$$F = 2.513(H)^{-0.184}$$

For mine development scheme "B":

$$F = 1.580(10^3)(H)^{-1.470}$$

Where:
F = Factor used to adjust cost
H = Height of the retorts



SCALE - LOGARITHMIC

8.1.1. MINE DEVELOPMENT
CAPITAL COST

8.1.2. PUMPS AND SHAFTS

The capital costs of pumps and shafts are significantly affected by the depth of the workings below the ground surface. The pumps are for the movement of the shale oil and the water produced by the retorting process. Shafts are constructed to provide access for men and materials, fresh air ventilation, and off-gas control. The cost of shafts and pumps are also affected by the retort height.

To obtain the costs for shafts and pumps, select the scheme of retorting and the adjusted production rate. Determine the cost at a 150 meter retort height and a lower access level depth of 400 meters. If either the retort height or the main access level depth is different, the cost obtained from the curve must be multiplied by one of the following factors:

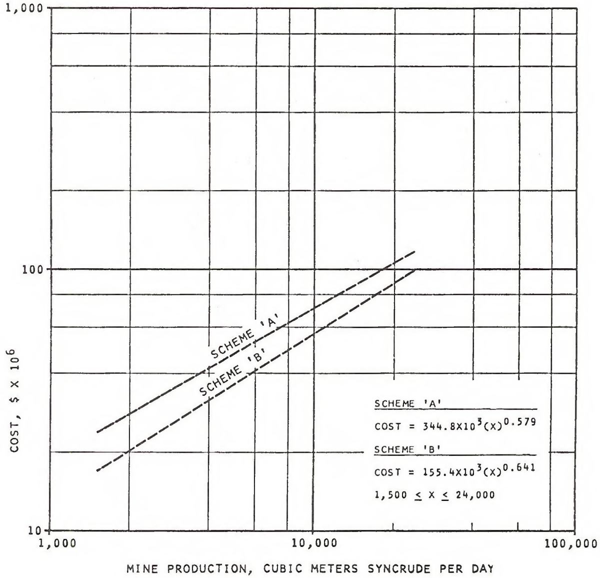
For retort scheme "A":

$$F = 4.57(10^{-3})(H)^{0.016}(D)^{0.886}$$

For retort scheme "B":

$$F = 1.92(10^{-2})(H)^{-0.126}(D)^{0.765}$$

Where:
F = Factor
H = Height of retort
D = Average depth of access level below shaft collars



SCALE - LOGARITHMIC

8.1.2. SHAFTS AND PUMPS
CAPITAL COST

8.1.3. MINE AND RETORT EQUIPMENT

Mine equipment is the equipment required to construct the access levels, gas off level and rubblize the retorts. Included are tunnel boring machines, raise borers, drills, front end loaders, conveyors, haul trucks, service trucks, crushers, personnel carriers and administrative equipment. The retort equipment consists of fans, duct work, pipelines, and air control equipment.

The mine and retort equipment is not affected by the depth of the mine workings below the surface, but is influenced to a significant degree by the height of the retort (note factors below).

To obtain the cost of mine and retort equipment, select the scheme of retorting desired, "A" or "B". After determining the cost for the scheme at 150 meters retort height, an adjustment for retorts of other heights may be made by using the following factors:

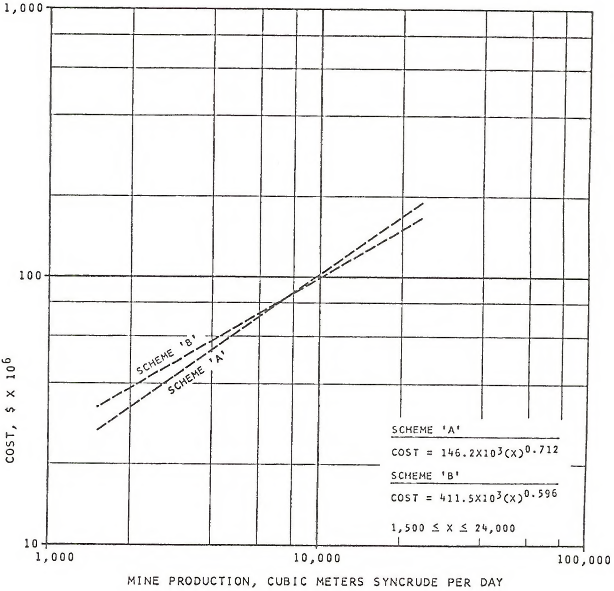
For retort scheme "A":

$$F = 11.07(H)^{-0.480}$$

For retort scheme "B":

$$F = 1730(H)^{-1.488}$$

Where:
F = Factor
H = Height of the retort



SCALE - LOGARITHMIC

8.1.3. MINE AND RETORT EQUIPMENT
CAPITAL COST

8.1.4. ELECTRIC POWER

The electric power facilities capital costs cover the main substation and surface distribution required for the operation of the in-situ process. Power lines to the site are provided by the utility company and the costs are recovered from the power consumption.

The surface electric power costs must be adjusted for height of retort and syncrude production. The curves are for the 150 meter high retort.

The factors for adjustment to the various retort heights are as follows:

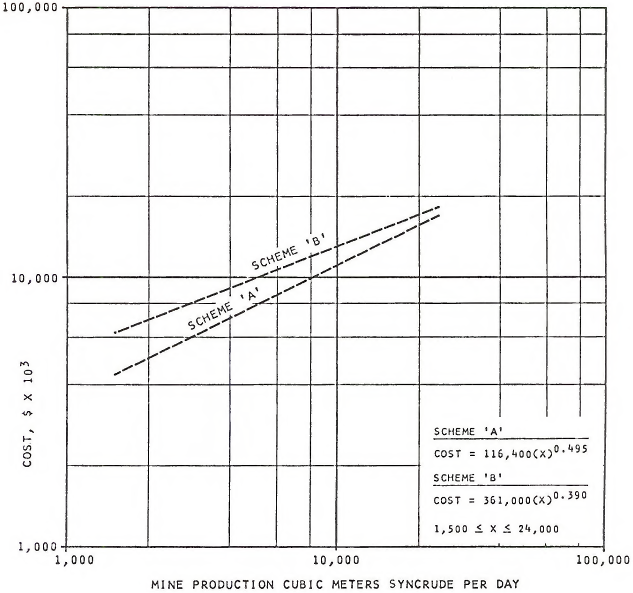
For retort scheme "A":

$$F = 0.00268(H)(T)^{-0.495}[(6.289)(T)]^{1.490}$$

For retort scheme "B":

$$F = 0.000266(H)^{1.500}(T)^{-0.390}[(6.289)(T)]^{3.200}$$

Where:
F = Factor
H = Height of retort in meters
T = Daily production of syncrude in cubic meters.
(Adjusted for grade of oil shale - Section 8.)



SCALE - LOGARITHMIC

8.1.4. ELECTRIC POWER
CAPITAL COST

8.1.5. SURFACE BUILDINGS

The surface buildings costs include all surface facilities for the in-situ process. The buildings are grouped in three categories (repair shops and warehouses, offices and changehouses) and are shown on two curves for clarity. The curves are shown on Figure 8.1.5.1., Retort Scheme "A", and Figure 8.1.5.2., Retort Scheme "B".

The surface buildings costs are not significantly affected by the depth of the workings, but are influenced by the height of the retort selected. The curves are all for the 150 meter retort.

8.1.5.1. RETORT SCHEME A

The factors for adjustment to the various retort heights other than 150 meters, are as follows:

Offices:

$$F = 0.131(H)^{0.122}(T)^{-0.774}[(6.289)(T)]^{1.173(H)^{-0.083}}$$

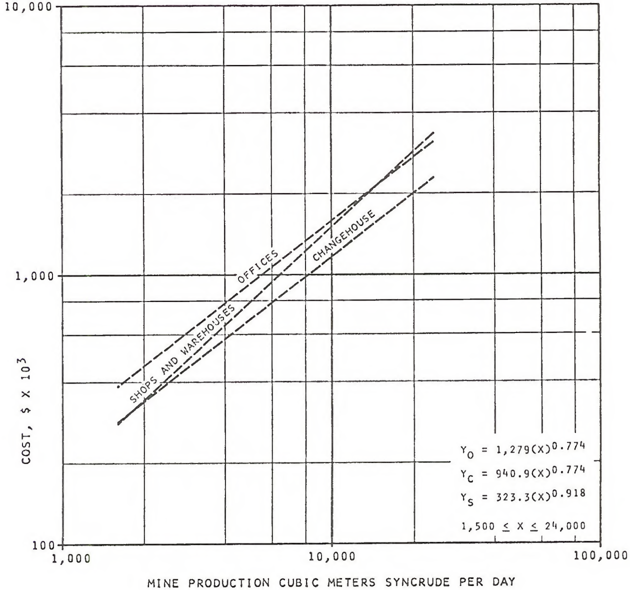
Changehouses:

$$F = 0.135(H)^{0.116}(T)^{-0.774}[(6.289)(T)]^{1.173(H)^{-0.083}}$$

Repair Shops and Warehouses:

$$F = 628.5(H)^{-1.623}(T)^{-0.918}[(6.289)(T)]^{0.412(H)^{0.160}}$$

Where:
F = Factor
H = Height of retort in meters
T = Daily production of syncrude in cubic meters
(Adjusted for grade of oil shale - Section 8.)



SCALE - LOGARITHMIC

8.1.5.1. SURFACE BUILDINGS - SCHEME 'A'
CAPITAL COST

8.1.5.2. RETORT SCHEME B

The factors for adjustment to the various retort heights other than 150 meters, are as follows:

Offices:

$$F = 0.430(H)^{-0.068}(T)^{-0.645}[(6.289)(T)]^{2.544}(H)^{-0.274}$$

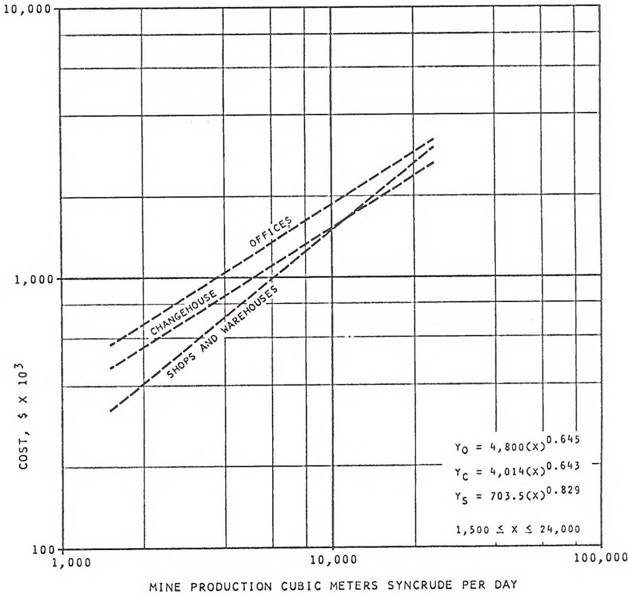
Changehouses:

$$F = 0.451(H)^{-0.077}(T)^{-0.643}[(6.289)(T)]^{2.525}(H)^{-0.273}$$

Repair Shops and Warehouses

$$F = 0.751(H)^{-0.247}(T)^{-0.829}[(6.289)(T)]^{0.761}(H)^{0.017}$$

Where:
F = Factor
H = Height of retort in meters
T = Daily production of syncrude in cubic meters (Adjusted for grade of oil shale - Section 8.)



SCALE - LOGARITHMIC

8.1.5.2. SURFACE BUILDINGS - SCHEME 'B'
CAPITAL COST

8.2. OPERATING COSTS

Operating costs are provided for the operation of the mine and retort functions. Operating costs are also provided for the operation of the surface facilities directly connected with the underground operation. Upgrading and other surface functions are covered in Sections 9. and 10.

8.2.1. MINE AND RETORTS

The operating costs are for the operation of the mine and the retorts including hoisting, excavating, rubblization and retort operation. curves are based on a retort height of 150 meters. The operating costs are significantly affected by the height of retort and an adjustment must be made for other heights. The depth from surface to the main level is 400 meters. No factor was developed for other depths. The depth affects the operating costs of few activities, therefore only a small error is introduced by not making an adjustment.

To obtain the operating cost, select the scheme desired and the adjusted production rate in cubic meters per day. Determine the cost for the 150 meter height retort, which must be multiplied by one of the following factors:

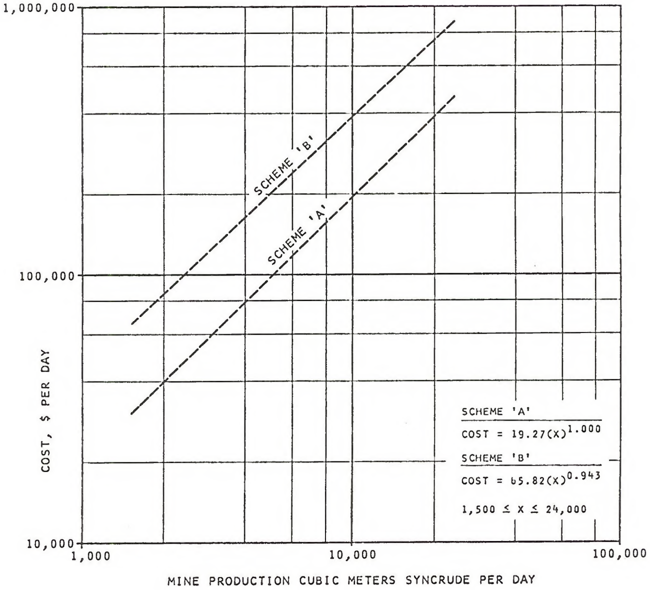
For retort scheme "A":

$$F = 185.2(H)^{-1.042}$$

For retort scheme "B":

$$F = 1069(H)^{-1.392}$$

Where:
F = Factor
H = Height of the retort



SCALE - LOGARITHMIC

8.2.1. MINE AND RETORTS
OPERATING COST

8.2.2. ADMINISTRATIVE EXPENSES

The administrative expenses are the costs incurred in the support activities of the mining effort. Included is mine management, engineering, geology, office, safety, security and top level supervision. Curves are provided for salaries and wages for the described functions. The administrative expenses curves include costs for operating the offices and other miscellaneous costs inherent in a mining operation not assignable to a specific work task. The administrative equipment operation curves are for the costs of operating the sedans, pick-ups and utility vehicles used in the described functions. A set of curves are provided for each scheme of modified in situ retorting.

8.2.2.1. RETORT SCHEME A

The height of retort has a significant effect on the costs of the Administrative Expenses. Curves are plotted for the 150 meter height of retort. For retorts of different heights, the resulting costs must be multiplied by the following factors:

Administrative Salaries

$$F = 11.25(H)^{-0.483}(T)^{-0.624}(T)^{0.469}$$

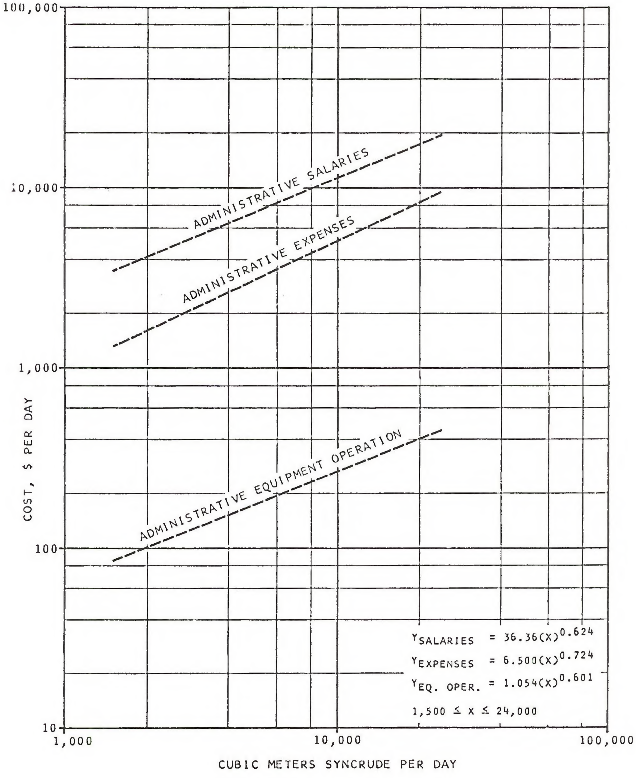
Administrative Expenses

$$F = 16.63(H)^{-0.561}(T)^{-0.724}(T)^{0.544}$$

Administrative Equipment Operation

$$F = 12.07(H)^{0.497}(T)^{-0.601}(T)^{0.438}$$

Where:
F = Factor
H = Height of retort in meters
T = Daily production of syncrude in cubic meters
(Adjusted for grade of oil shale - Section 8.)



SCALE - LOGARITHMIC

8.2.2.1. GENERAL EXPENSE - SCHEME 'A'
OPERATING COST

8.2.2.2. RETORT SCHEME B

The height of retort has a significant effect on the costs of the Administrative Expenses. Curves are plotted for the 150 meter height of retort. For retorts of different heights, the resulting costs must be multiplied by the following factors:

Administrative Salaries

$$F = 3.057(H)^{-0.223}(T)^{-0.603}(T)^{0.557}(H)^{0.016}$$

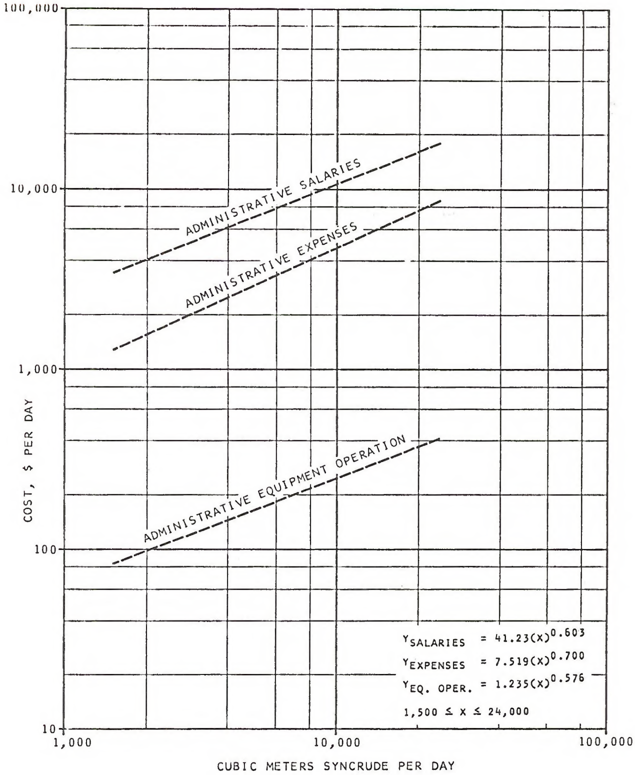
Administrative Expenses

$$F = 3.679(H)^{-0.260}(T)^{-0.700}(T)^{0.643}(H)^{0.017}$$

Administrative Equipment Operation

$$F = 2.356(H)^{-0.171}(T)^{-0.576}(T)^{0.551}(H)^{0.009}$$

Where:
F = Factor
H = Height of retort in meters
T = Daily production of syncrude in cubic meters
(Adjusted for grade of oil shale - Section 8.)



SCALE - LOGARITHMIC

8.2.2.2. GENERAL EXPENSE - SCHEME 'B'
OPERATING COST

8.2.3. GENERAL SERVICES

This item is intended to cover those work tasks not directly attributable to a specific mine operation. Included is delivery of materials and supplies, maintenance of roads, service and maintenance of communications, electrical maintenance, sanitation and housekeeping facilities.

Curves are provided for labor, supplies and equipment operation for both schemes of modified in situ retorting and are so designated on the figure.

8.2.3.1. RETORT SCHEME A

The height of retort has a significant effect on the costs of the general services. Curves are plotted for the 150 meter height of retort. For retorts of different heights, the resulting costs must be multiplied by the following factors:

Labor

$$F = 14.67(H)^{-0.536}(T)^{-0.834}(T)^{0.679}(H)^{0.041}$$

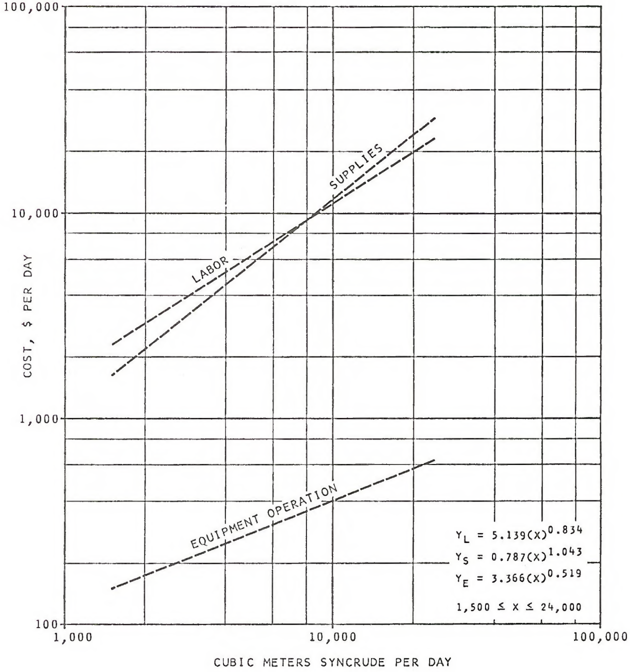
Supplies

$$F = 56.77(H)^{-0.806}(T)^{-1.043}(T)^{0.784}(H)^{0.057}$$

Equipment Operation

$$F = 9.251(H)^{-0.444}(T)^{-0.519}(T)^{0.371}(H)^{0.067}$$

Where:
F = Factor
H = Height of retort in meters
T = Daily production of syncrude in cubic meters
(Adjusted for grade of oil shale - Section 8.)



SCALE - LOGARITHMIC

8.2.3.1. GENERAL SERVICES - SCHEME 'A'
OPERATING COST

8.2.3.2. RETORT SCHEME B

The height of retort has a significant effect on the costs of the general services. Curves are plotted for the 150 meter height of retort. For retorts of different heights, the resulting costs must be multiplied by the following factors:

Labor

$F = 5.490 \times 10^{6}(H)^{-3.097}(T)^{-1.015}(T)^{0.168}(H)^{0.359}$

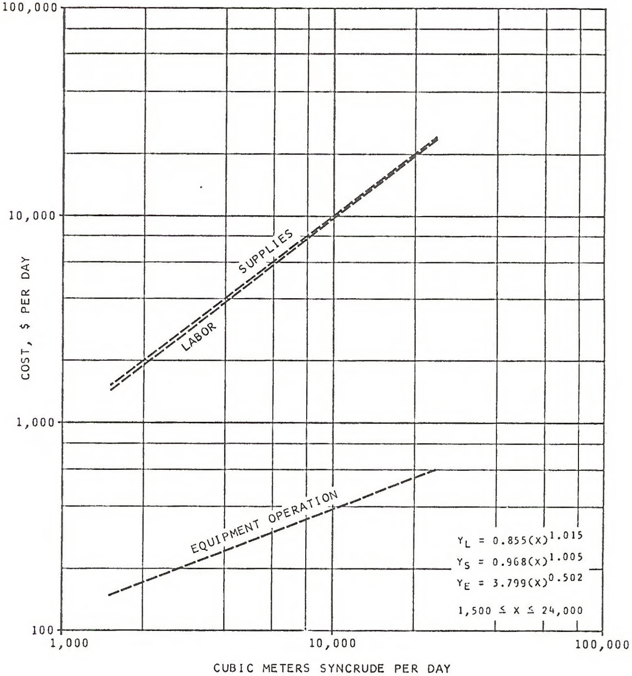
Supplies

$F = 6.578(H)^{-0.376}(T)^{-1.005}(T)^{0.928}(H)^{0.016}$

Equipment Operation

$F = 2.738(H)^{-0.201}(T)^{-0.502}(T)^{0.454}(H)^{0.020}$

Where:
F = Factor
H = Height of retort in meters
T = Daily production of syncrude in cubic meters
(Adjusted for grade of oil shale - Section 8.)



SCALE - LOGARITHMIC

8.2.3.2. GENERAL SERVICES - SCHEME 'B'
OPERATING COST

9. UPGRADING

Upgrading is the refining or improving of retorted shale oil by removing the impurities, such as sulfur, and by converting the syncrude into more useful forms.

The collection of processes used in upgrading can vary, depending on the size of the upgrading plant and the desired products. A small refinery of 1500 to 5000 cubic meters per day input could typically employ basic fractionation, thermal cracking, and sulfur recovery. These processes would produce a less viscous, pipelineable syncrude. A medium size refinery, with inputs from the retorts of from 4000 to 24,000 cubic meters per day, and utilizing a more complete system of processes such as those noted in Table 9., could produce several petroleum products and by products.

The capital and operating costs for upgrading syncrude were developed by creating a slate of the upgrading processes likely to be used by a typical refinery operator.

Drawing 9.a. illustrates the relationships between the various process elements in a hypothetical small upgrading plant. Drawing 9.b. shows the similar relationships in a hypothetical medium upgrading plant. For the purpose of simplicity, these block flow diagrams do not indicate the upgrading support equipment such as water treatment, steam generation, air compression, and cooling towers. The capacities of the processes shown on these diagrams can be found in Table 9.

Abbreviations Used In Table 9., Drawing 9.a. and Drawing 9.b.

BPD	Barrels per day (U.S. Standard at 42 gallons per barrel)
CMPD	Cubic meters per day
CMPMT	Cubic meters per metric ton
KCMPD	Thousand cubic meters per day
MSCMPD	Million standard cubic meters per day
MTPD	Metric tons per day

TABLE 9.

SYNCRUDE UPGRADING PROCESSES AND CAPACITIES

Values x 1,000

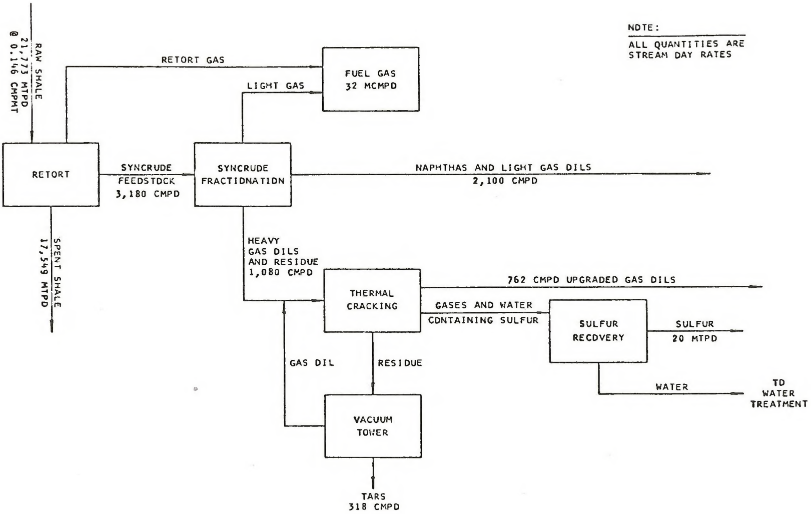
UPGRADING CAPACITY								
	BPD	10	20	30	40	50	100	150
	CMPD	1.590	3.180	4.770	6.360	7.950	15.900	23.850
INTERNAL USE PRODUCTS								
To Thermal Cracking	CMPD	0.540	1.080	1.620				
Naphthas to Naphtha Hydrotreater	CMPD			0.954	1.272	1.590	3.180	4.770
Gas Oils to Gas Oil Hydrotreater	CMPD			3.816	5.088	6.360	12.720	19.080
Residues to Coking Plant	CMPD			1.050	1.400	1.750	3.500	5.250
Hydrogen Plant Output	KCMPD			1.645	2.194	2.742	5.485	8.227
UPGRADED SYNCRUDE								
Crude Shale Oil to Fractionator	CMPD	1.590	3.180	4.770	6.360	7.950	15.900	23.850
Combined Naphthas and Gas Oils	CMPD	1.050	2.100	3.150				
Upgraded Gas Oils	CMPD	0.381	0.762	1.140				
Hydrotreated Naphthas	CMPD			1.072	1.430	1.787	3.574	5.361
Hydrotreated Gas Oils	CMPD			4.060	5.414	6.767	13.534	20.301
TOTAL SYNCRUDE	CMPD	1.431	2.862	5.132*	6.844	8.554	17.108	25.662

* 4.290 for lower range plant using thermal cracking.

OTHER PRODUCTS								
Ammonia	MTPD			0.099	0.132	0.165	0.330	0.495
Sulfur from:								
Crude Shale	MTPD	0.010	0.020	0.030	0.040	0.050	0.100	0.150
Retort Gases	MTPD			0.022	0.030	0.038	0.075	0.112
Plant Fuel Gas:								
Low BTU	KCMPD			116	155	194	388	582
High BTU	KCMPD	16	32	26**	34	43	86	129

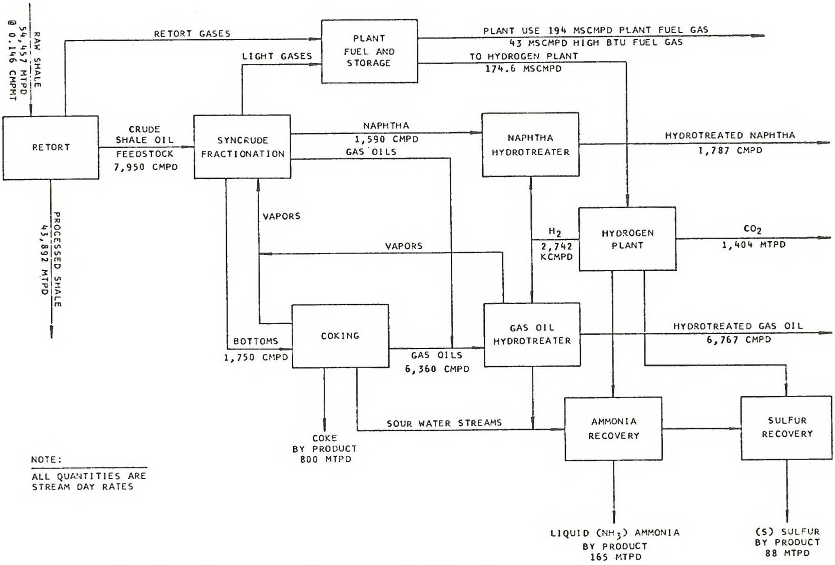
** 48 for lower range plant using thermal cracking.

Tars	CMPD	0.159	0.318	0.477				
Carbon Dioxide	MTPD			0.842	1.123	1.404	2.808	4.212
Coke	MTPD			0.480	0.640	0.800	1.600	2.400


RAW SHALE
21,773 MTPD
@ 0.146 CMPMT
RETORT GAS
FUEL GAS
32 MCMPD
LIGHT GAS
NOTE:
ALL QUANTITIES ARE STREAM DAY RATES
RETORT
SYNCRUDE
FEEDSTOCK
3,180 CMPD
SYNCRUDE
FRACTIONATION
NAPHTHAS AND LIGHT GAS OILS
2,100 CMPD
SPENT SHALE
17,549 MTPD
HEAVY
GAS OILS
AND RESIDUE
1,080 CMPD
THERMAL
CRACKING
762 CMPD UPGRADED GAS OILS
GASES AND WATER
CONTAINING SULFUR
SULFUR
RECOVERY
SULFUR
20 MTPD
GAS OIL
RESIDUE
WATER
TO
WATER
TREATMENT
VACUUM
TOWER
TARS
318 CMPD

TYPICAL BLOCK FLOW DIAGRAM OF 1,590 CMPD AND 3,180 CMPD 'LOWER' UPGRADING PLANTS
SHOWING MATERIAL BALANCE FOR 3,180 CMPD (20,000 BPD)

DRAWING 9.a.


RAW SHALE
54,457 MTPD
@ 0.146 CMPMT
RETORT GASES
PLANT FUEL AND STORAGE
PLANT USE 194 MSCMPD PLANT FUEL GAS
43 MSCMPD HIGH BTU FUEL GAS
LIGHT GASES
TO HYDROGEN PLANT
174.6 MSCMPD
RETORT
CRUDE SHALE OIL FEEDSTOCK
7,950 CMPD
SYNCRUDE FRACTIONATION
NAPHTHA
1,590 CMPD
GAS OILS
NAPHTHA HYDROTREATER
HYDROTREATED NAPHTHA
1,787 CMPD
PROCESSED SHALE
43,892 MTPD
VAPORS
VAPORS
H2
2,742 KCMPD
HYDROGEN PLANT
CO2
1,404 MTPD
COKING
BOTTOMS
1,750 CMPD
GAS OILS
6,360 CMPD
GAS OIL HYDROTREATER
HYDROTREATED GAS OIL
6,767 CMPD
SOUR WATER STREAMS
AMMONIA RECOVERY
SULFUR RECOVERY
COKE
BY PRODUCT
800 MTPD
LIQUID (NH3) AMMONIA
BY PRODUCT
165 MTPD
(S) SULFUR
BY PRODUCT
88 MTPD

NOTE:
ALL QUANTITIES ARE STREAM DAY RATES

TYPICAL BLOCK FLOW DIAGRAM OF MEDIUM UPGRADING PLANTS
SHOWING MATERIAL BALANCE FOR 7,950 CMPD (50,000 BPD)

DRAWING 9.b.

9.1. CAPITAL COSTS

Capital costs for the upgrading facilities except delayed coking are based on the process output capacity. Liquid outputs are expressed in cubic meters per day, or metric tons per day. Gaseous outputs are expressed in million cubic meters per day. Capital costs for delayed coking process are based on coker feed stock in cubic meters per day. The cost of a capital item may be determined by calculating the required output of the particular process, and then referring to the appropriate curve, reading the estimated cost directly.

Adjustments for changes in capital costs due to periodic variations in the cost of labor and materials may be made by using the cost index shown in Section 2.3., Item 7. for Refineries Construction as covered by the Oil and Gas Journal Nelson Operating Cost Index.

If changes in the demand for upgraded syncrude products should require revised outputs or a new slate of upgrading products with an attendant change in the number or size of process units, the costs of the larger or smaller units can be obtained from the cost versus output curves which have been developed for each of the upgrading processes.

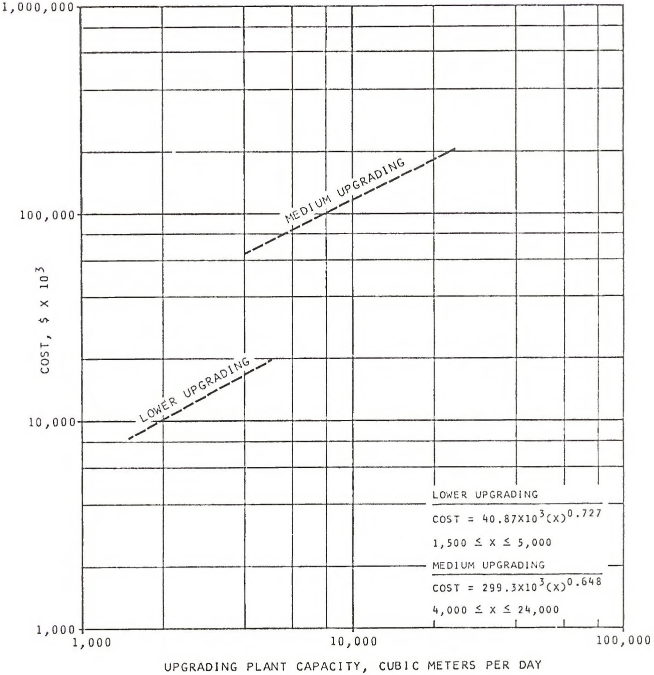
Table 9. relates the quantity of syncrude to be fractionated to the output of upgraded shale oil for each size plant module. If the user selects a slate that differs from that shown in Table 9., then determine the capital costs as follows:

Sections For Plants Using Thermal Cracking	Sections For Plants Using Hydrotreating
9.1.2.	9.1.2.
-	9.1.3.
-	9.1.4.
9.1.5.	-
-	9.1.6.
9.1.7.	9.1.7.
-	9.1.8.
-	9.1.9.
9.1.10.	9.1.10.

If the slate from Table 9. is selected, then determine the capital cost by using Section 9.1.1. for the composite plant.

9.1.1. SYNCRUDE UPGRADING - COMPOSITE PLANT CAPITAL COST

These curves represent a composite plant. If the user wishes to vary the capacities shown in Table 9., the total cost can be found by adding the process costs for each upgrading plant process separately shown in Figures 9.1.2. through 9.1.10.

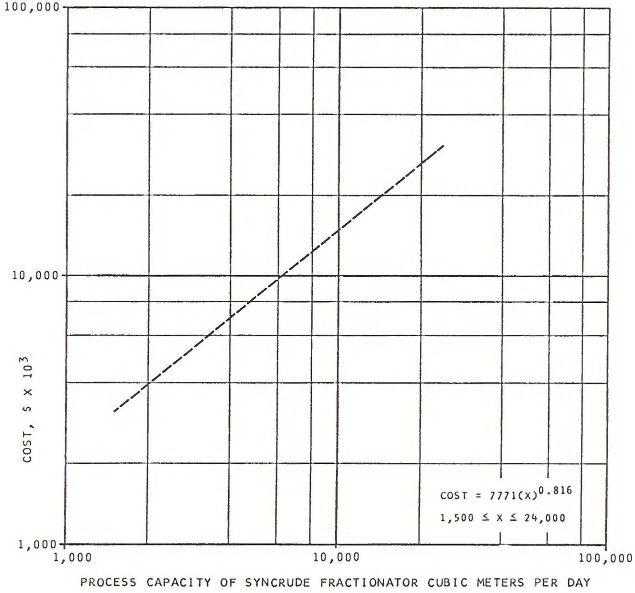


SCALE - LOGARITHMIC

9.1.1. SYNCRUDE UPGRADING
TOTAL PLANT CAPITAL COST

9.1.2. SYNCRUDE FRACTIONATION

Fractionation means the distillation and separation of the various "cuts" or boiling point ranges that make up syncrude. The syncrude is first heated to about 340°C and then passed to the fractionating tower. In some situations, this heating stage is accomplished in the retort process. A typical fractionating column contains a series of horizontal "bubble trays" in which the hydrocarbon gases condense. Those compounds with high boiling point ranges, (gas oil and residue), condense in the lower trays. Low boiling point ranges, (kerosene and gasoline), condense in the upper trays. The liquid is then drawn off from specific trays and passed on for further processing.

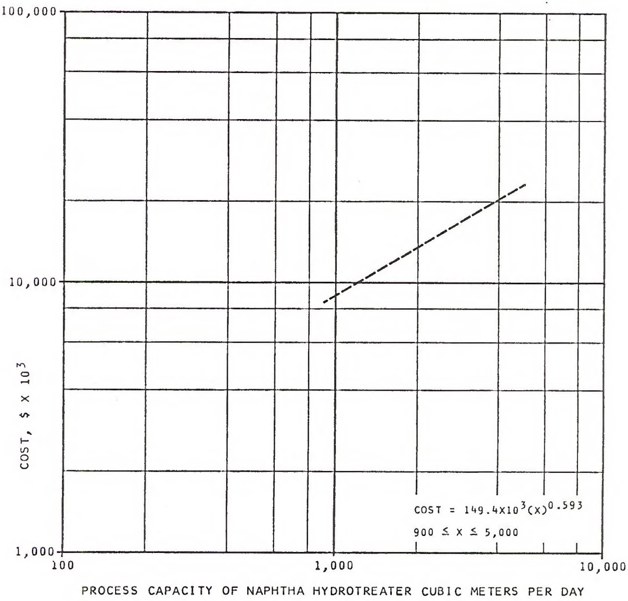


SCALE - LOGARITHMIC

9.1.2. SYNCRUDE FRACTIONATION
CAPITAL COST

9.1.3. NAPHTHA HYDROTREATING

Naphtha is produced during fractionation and during coking and gas oil hydrotreating as one of the low boiling point fractions. Naphtha is catalytically reacted with hydrogen to remove sulfur as hydrogen sulfide and nitrogen as ammonia; and to saturate and stabilize any unsaturated naphthenes. Sulfur content is reduced approximately 90% and nitrogen is reduced approximately 85%. An absorber removes dissolved gases from the naphtha which is then ready for storage and blending.

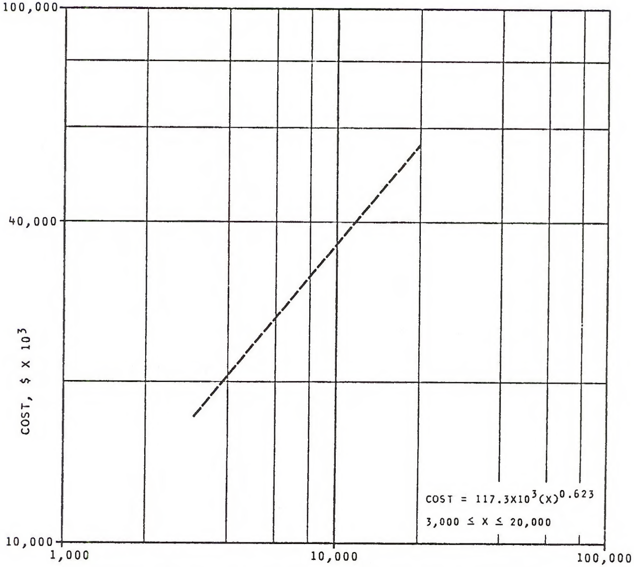


SCALE - LOGARITHMIC

9.1.3. NAPHTHA HYDROTREATING
CAPITAL COST

9.1.4. GAS OIL HYDROTREATING

Raw gas oil is produced as a middle cut in fractionation and in coking. Gas oil is hydrotreated in a process similar to hydrotreating naphtha.

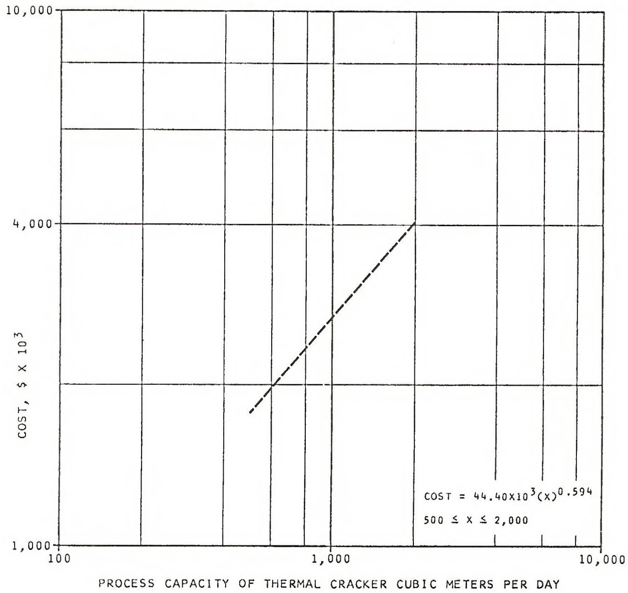


SCALE - LOGARITHMIC

9.1.4. GAS OIL HYDROTREATING
CAPITAL COST

9.1.5. THERMAL CRACKING

The thermal cracking plant is typically used in the smaller upgrading facilities. This process is used to convert the middle cut gas oil into lower pour point fractions. The gas oil is heated and cracked (decomposed under high temperature) to produce upgraded syncrude composed of gas, naphtha, and gas oils. A vacuum tower further separates the residue produced in cracking into gas oil and tar. The gas oil produced in the vacuum unit is cycled back to the cracker to be processed with the feed stock.



SCALE - LOGARITHMIC

9.1.5. THERMAL CRACKING
CAPITAL COST

9.1.6. DELAYED COKING

The delayed coking plant is associated with the larger upgrading facilities. Residue feed stock from the initial fractionation and other processes is charged to a coker fractionator where light fractions are removed and processed. The residue from the coker fractionator is heated to coking temperature and passed to one of the coke drums where the coking reaction takes place. Vapors from the coke drum are returned to the fractionator and separated.

When the amount of coke in the on-stream coker drum reaches the drum's capacity, the flow from the heater is diverted to another drum. The full drum is then emptied by steam jets and the coke is steam-stripped to remove any oils and gases. Any water in the coke is removed and sent with the used steam to the ammonia recovery unit. The coke product is crushed and stored for sale or disposal.

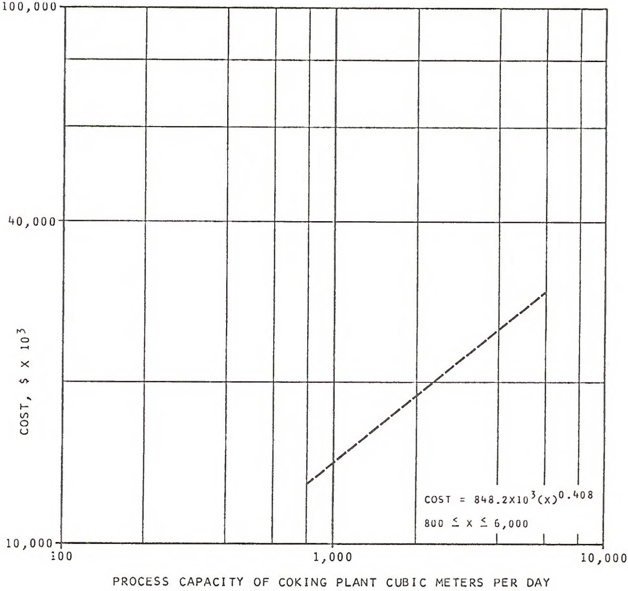
To determine the coke production for values other than those shown in Table 9., use the following.

$$P = 0.457(R)$$

Where:

P = Coke production in metric tons per day

R = Residue feed to coking plant in cubic meters per day

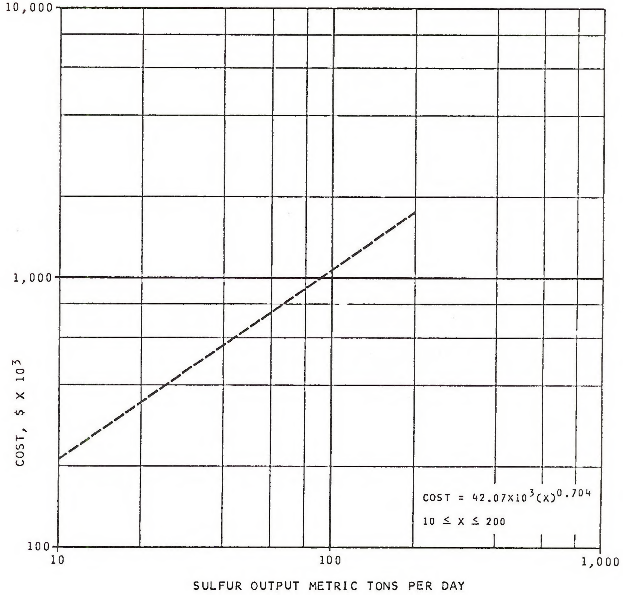


SCALE - LOGARITHMIC

9.1.6. DELAYED COKING
CAPITAL COST

9.1.7. SULFUR RECOVERY

Gases and water containing sulfur from the delayed coker, hydrotreating, and cracker units are scrubbed with aqueous solutions and recycled in a closed circuit. A Claus type sulfur recovery process is used to remove sulfur from the scrubber liquids. In larger upgrading plants, a Wellman-Lord recovery process is utilized in addition to the Claus process.



SCALE - LOGARITHMIC

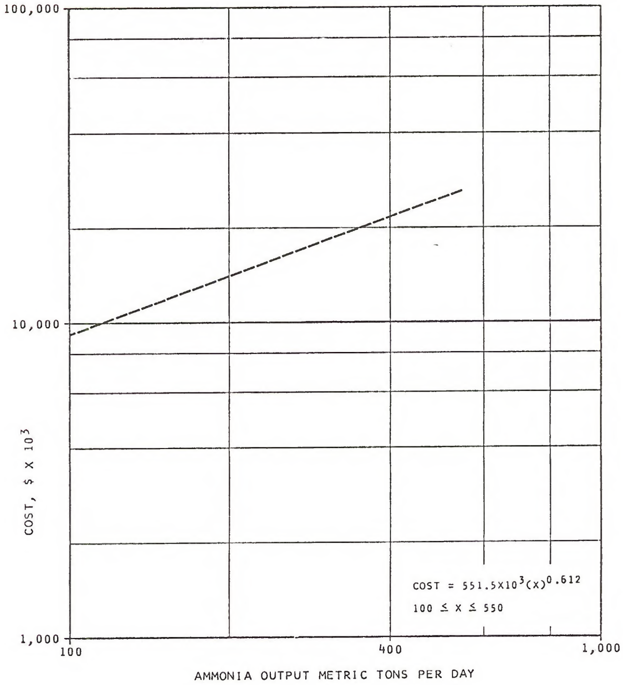
9.1.7. SULFUR RECOVERY
CAPITAL COST

9.1.8. AMMONIA RECOVERY

Ammonia is recovered from water streams in the delayed coker, hydrogen plant and hydrotreaters as well as from low kilojoule plant gases.

The water streams are degassed to remove light hydrocarbons which in turn are combined with the above low kilojoule hydrocarbons plant gases. The combined gas stream is then compressed and passed to the ammonia extraction unit. The degassed water is next fed to a "sour water stripper" where dissolved ammonia, hydrogen sulfide and carbon dioxide are separated by steam stripping, and sent as gases to the ammonia extraction unit.

In the extraction unit, ammonia is reccvered from the gas streams by selective absorbtion, compressed and condensed to a marketable product.

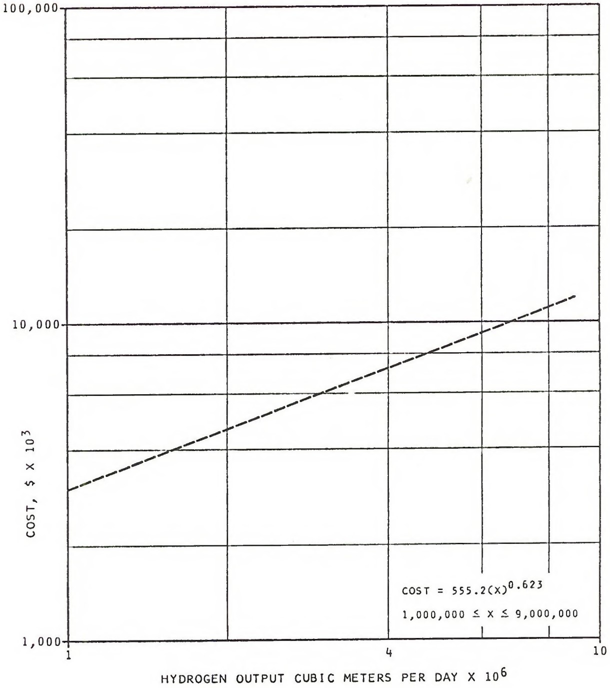


SCALE - LOGARITHMIC

9.1.8. AMMONIA RECOVERY
CAPITAL COST

9.1.9. HYDROGEN PRODUCTION

High purity hydrogen is needed for the naphtha hydrotreating and gas oil hydrotreating processes. This hydrogen is produced by partial oxidation of shale oil residue.



SCALE - LOGARITHMIC

9.1.9. HYDROGEN PRODUCTION
CAPITAL COST

9.1.10. UPGRADING SUPPORT EQUIPMENT

Figure 9.1.10. contains capital cost curves for upgrading support equipment noted below. Upgrading support plant capacity is based on cubic meters per day of syncrude product to the upgrading process.

9.1.10.1. WATER TREATMENT

Water needed for the cooling tower, steam generation, and upgrading plant processes is clarified and filtered in the water treatment plant. Boiler feed water is softened while all other processes use water directly from the treatment plant.

9.1.10.2. COOLING TOWERS

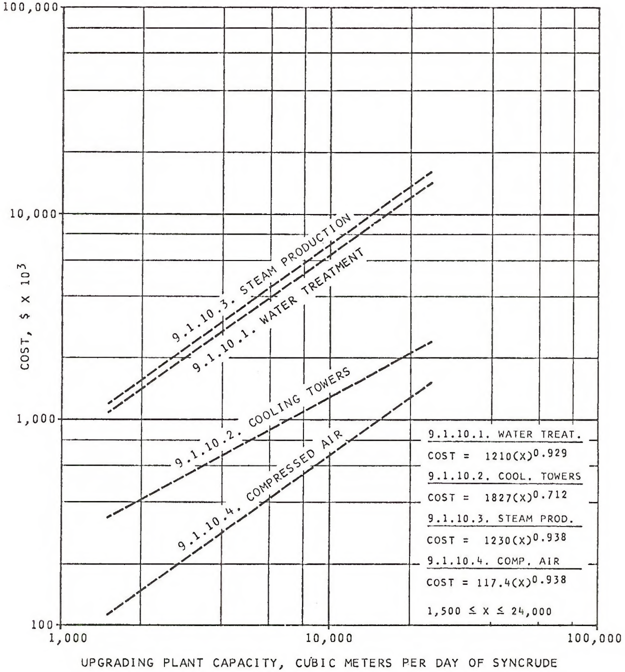
A cooling tower system provides cooled water for the upgrading plant processes. An automatic chemical control system monitors the water quality in the cooling tower system.

9.1.10.3. STEAM PRODUCTION

Steam is generated by boilers using feedwater from the treatment plant. Steam pressures range from 0.352 to 98.41 kilograms per square centimeter.

9.1.10.4. COMPRESSED AIR

Air is compressed, cooled, dried, filtered and stored for use in the upgrading plant instrument system.



SCALE - LOGARITHMIC

9.1.10. UPGRADING SUPPORT EQUIPMENT
CAPITAL COST

9.2. OPERATING COST

Retorting and upgrading plants in this handbook are divided into two modules of capacity as follows:

Size	Plant Capacity (Cubic meters per day)
Lower range	1,590 to 5,000
Medium range	4,000 to 23,850

The operating costs are based on upgrading plants of the configuration indicated in Table 9. Should a different slate than that listed in the table be specified, the user may adjust the supplies and equipment operation costs in a direct ratio of the adjusted upgrading plant capital cost to the basic composite upgrading plant cost. No adjustment to labor cost is required.

9.2.1. SYNCRUDE UPGRADING - COMPOSITE PLANT OPERATING COST

Operating costs have been separated into the following three categories:

1. Labor, pertains to both an operating labor force and a maintenance labor force. Operating supervisors are also included in this category at 10% of the total operating labor force.

2. Supplies, incorporates the following expenses:

   a. Raw water charges
   b. Purchase power
   c. Chemicals and catalysts
   d. Miscellaneous supplies

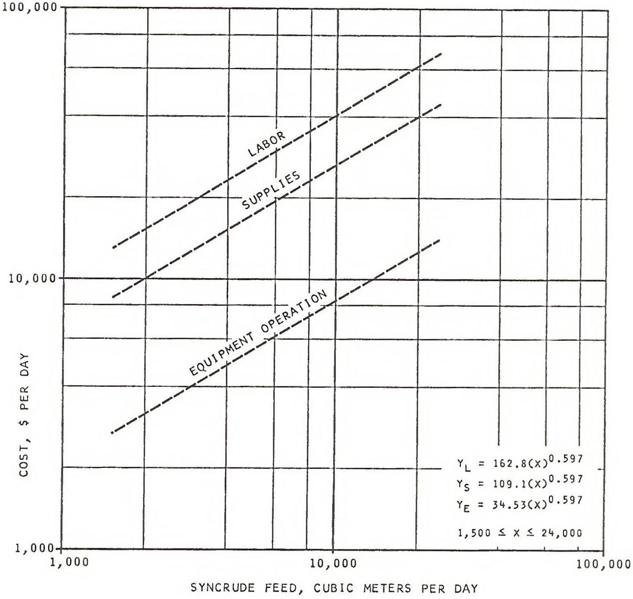
   Fuel is not purchased since it is produced in the upgrading plant or related operation.

3. Equipment Operation refers to the maintenance of all the plant's facilities including piping, vessels, valves, tanks, etc. This expense results from the following factors:

   a. Corrosion
   b. Erosion
   c. Temperature
   d. Pressure
   e. Vacuum

   This cost includes the purchase of piping, structural shapes, and other materials for plant maintenance.

For the purpose of adjusting operating costs to time frames other than July 1976, an index is provided in Section 2.3., Item 3., "Refineries (Operation)".



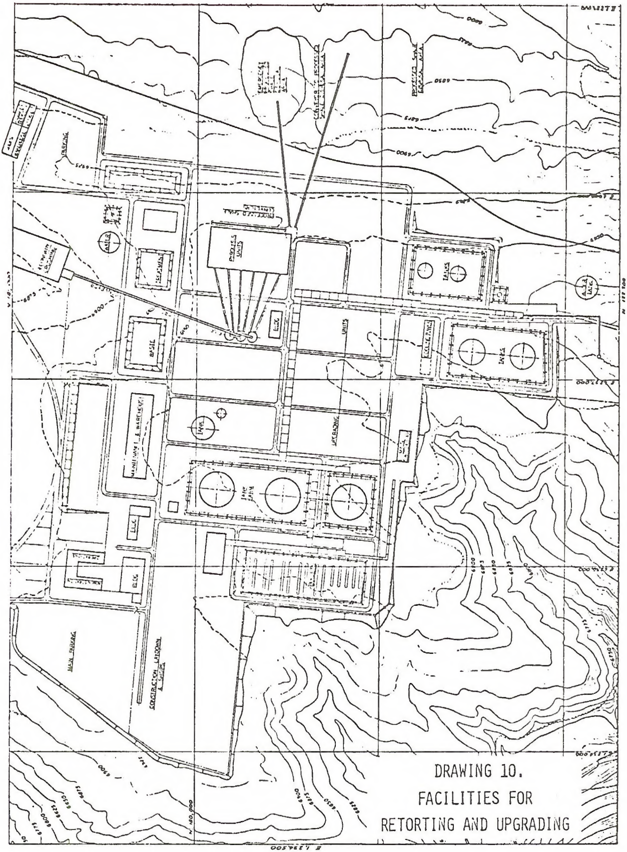
SCALE - LOGARITHMIC

9.2.1. SYNCRUDE UPGRADING
TOTAL PLANT OPERATING COST

10. FACILITIES FOR RETORTING AND UPGRADING

Facilities required for the operation and support of commercial scale retorting and upgrading operations are considered as being combined at a single location. This arrangement is typical of plant layouts in the petro-chemical industries. It consists of common site improvements, utility services, and buildings for administration, employee services, operations control, storage, maintenance, etc., as well as other essentials such as plant security and fire protection. Provisions are included for site restoration upon completion of operations.

Drawing 10. illustrates a typical layout of facilities for retorting and upgrading.


PARKING
BASIN
TREATMENT
PROCESS UNITS
BLDG
UNITS
TANKS
MAINTENANCE & WAREHOUSE
TANK
UPGRADING
TANK FARM
MAIN PARKING
CONSTRUCTION LAYDOWN & SHOPS

DRAWING 10.
FACILITIES FOR
RETORTING AND UPGRADING

10.1. CAPITAL COSTS

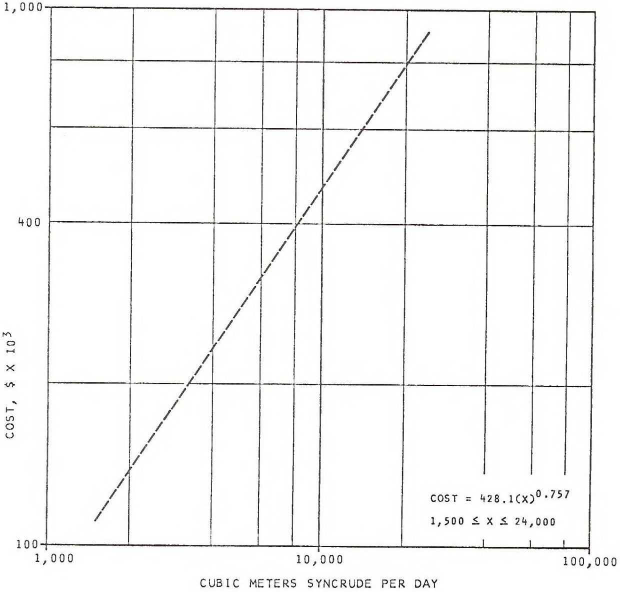
Capital costs for each element of the facility have been developed on the basis of the estimated support requirements for a given increment of retorting and upgrading. Provision has been included with each of these elements for meeting typical plant facilities engineering criteria such as the special requirements likely to be caused by the plant being located some distance from other similar operations, or away from the regular sources of supply for replacement parts, equipment, and materials. Provision has also been made for reserve storage of water and plant fuel.

Adjustments for escalation in the capital costs of facilities may be made by application of the cost index for "Refineries (Constr.)" shown in Section 2.3., Item 7.

10.1.1. SITE DEVELOPMENT

Site development costs shown by the following curve include all costs, exclusive of land acquisition, which are related to converting a relatively level area requiring a minimum of excavation or fill into an area ready to accommodate the construction of a retorting/upgrading complex for the daily processing of a specified amount of syncrude.

Capital costs contained in this item include general site engineering, clearing, and grading.



SCALE - LOGARITHMIC

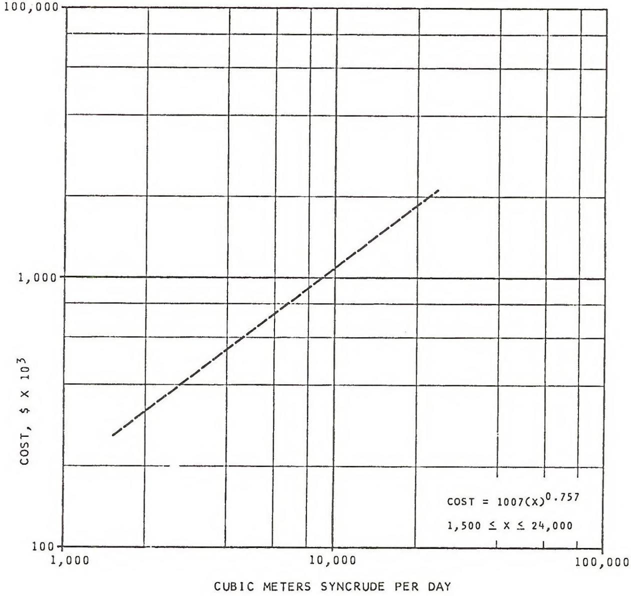
10.1.1. SITE DEVELOPMENT
CAPITAL COST

10.1.2. DRAINAGE AND SEWERS

An allocation for drainage and sewer cost is based on the following criteria for these facilities.

1. Meet drainage requirements for snow melt runoffs and heavy storm flows as well as the runoff generated by ordinary rainfall and watering operations. This also covers both improved and unimproved portions of a fairly level plant site.

2. Collect and recycle sewage flows generated by the combined population of plant personnel, construction personnel and visitors. This curve is based on an average daily water use of 0.38 cubic meters per capita.



SCALE - LOGARITHMIC

10.1.2. DRAINAGE AND SEWERS
CAPITAL COST

10.1.3. UTILITY SERVICES

This section presents costs based on the probable requirements for the following utilities. These are considered to be regularly required in connection with operating a retorting/upgrading plant.

10.1.3.1. ELECTRICAL DISTRIBUTION

Electrical service is by way of transmission lines from an established utility company's grid to the plant site.

The cost of the power line from the utility company grid to the main substation is absorbed by the utility company and is recovered during a contract period by the use rate and is covered in this handbook as an operating cost.

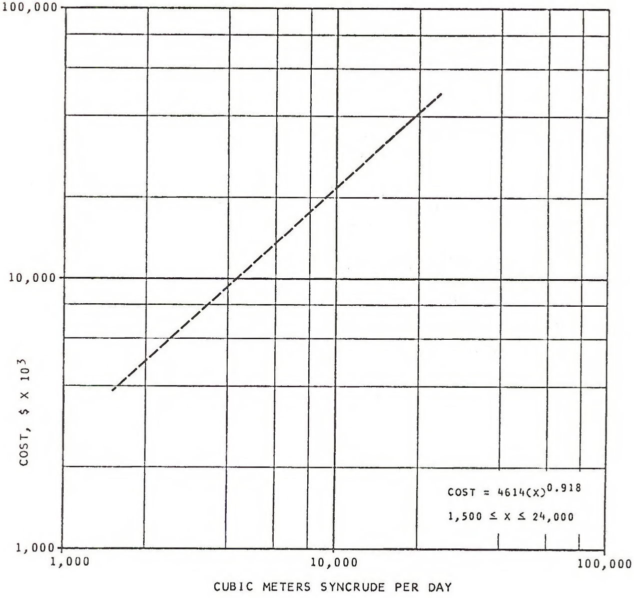
Capital costs for electrical facilities include the installation of a main plant substation and erection of main power transmission lines from the main substation to the following principal power use points:

1. Mine and crushing operations

2. Plant facilities
   a. Building and yard
   b. Retorting installation
   c. Upgrading

3. Pumping plants and shipping facilities.

The capital costs presented in the curve for electrical facilities cover the capital expenditures for the main substation and in-plant electrical installations to the above noted power use points.



SCALE - LOGARITHMIC

10.1.3.1. ELECTRICAL DISTRIBUTION
CAPITAL COST

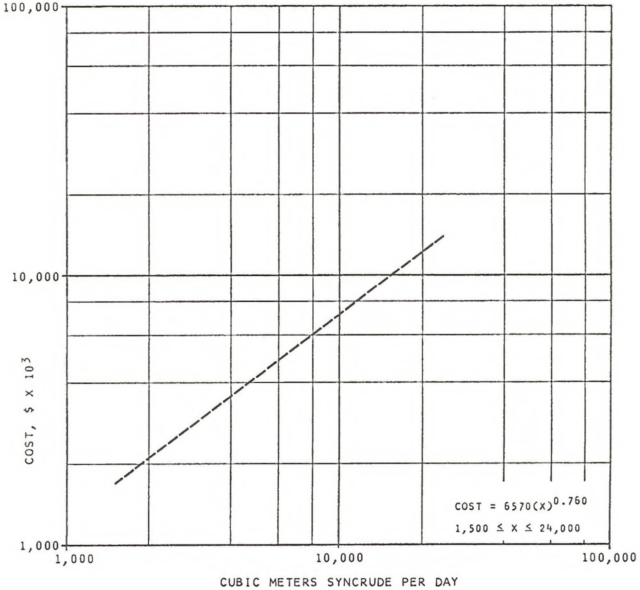
10.1.3.2. WATER SUPPLY

Water supply for the support facilities for retorting and upgrading is based on cubic meters per day of syncrude product from the retorting plant.

The capital cost for water supply includes the cost of the facilities for providing the make-up water required for the oil shale complex. The water will be obtained from surface stream flow or from underground sources. The costs are for dams, intakes, pumps and pipelines in the case of stream flow. Wells, pumps and pipelines were considered in the case of subsurface sources.

The wide variation in water requirements predicted for different oil shale complexes and the lack of definitive water sources are recognized. The curve provides a cost that is representative of the complexes evaluated.

Storage tanks and fire protection reserve tanks are included in Sections 10.1.7. and 10.1.8.



SCALE - LOGARITHMIC

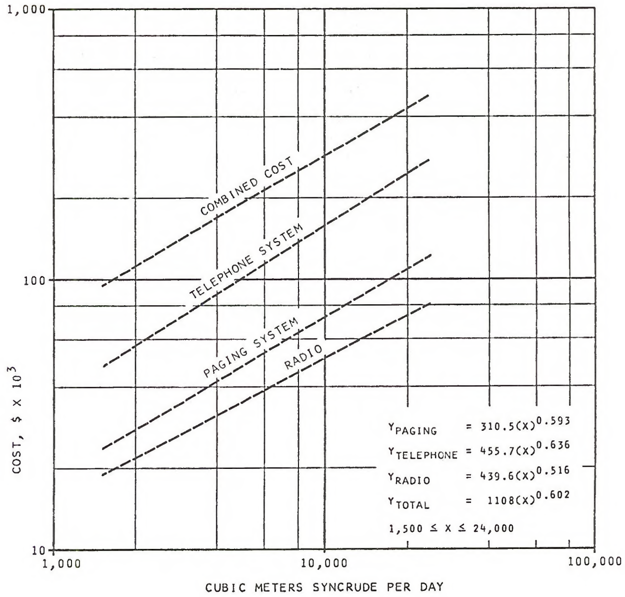
10.1.3.2. WATER SUPPLY
CAPITAL COST

10.1.3.3. COMMUNICATIONS SYSTEMS

The capital costs are for providing audio communications systems. Three types are included in the curve.

1. A "beeper" type of radio paging system for contacting supervisory plant and operator personnel.
2. In-plant telephone services via an aerial and/or underground cable network with a central switchboard.
3. A radio network for contact with security and pipeline patrol units and remote plant installations such as pumping stations.

The cost for each utility is obtained by selecting the syncrude production rate and reading the cost directly from the appropriate intercept.



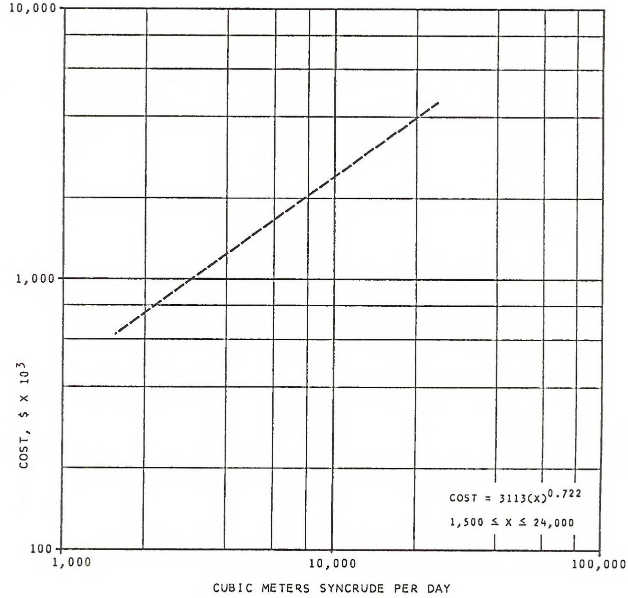
SCALE - LOGARITHMIC

10.1.3.3. COMMUNICATIONS SYSTEMS
CAPITAL COST

10.1.3.4. UTILITY SUPPORT

Pipe racks and utility trenches are an integral feature of the retorting/upgrading complex. They support, contain and protect the network of piping and conduits which must be installed at these facilities. The cost of this installation is affected by several variables such as actual plant layout and topography in addition to the management's own approaches toward the product "slate" and plant expansion.

The capital cost curve is based on a combination of pipe racks and utility trenches typical for retorting/upgrading plants with outputs ranging between 1,500 and 24,000 cubic meters of syncrude per day. Capital items include structural steel units set on concrete footings and reinforced concrete utility trenches.



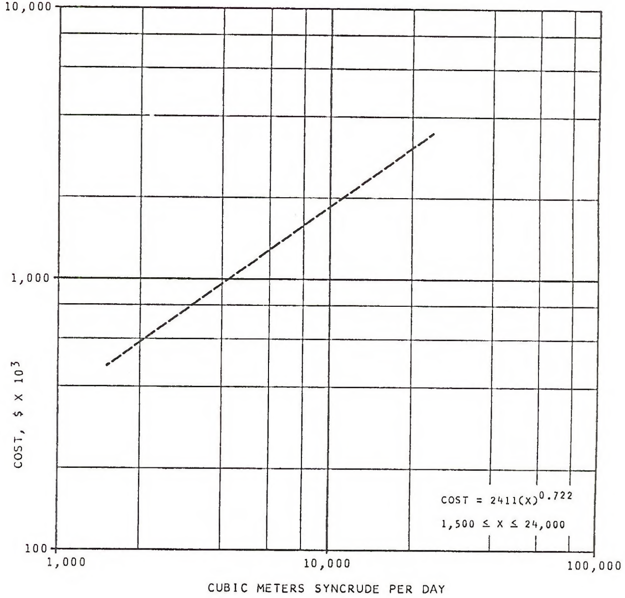
SCALE - LOGARITHMIC

10.1.3.4. UTILITY SUPPORT

CAPITAL COST

10.1.3.5. ALARMS AND INSTRUMENTATION

Capital costs shown on the curve for this item are for typical requirements for retorting/upgrading facilities producing between 1,500 and 24,000 cubic meters of syncrude per days. These costs do not include the communications, compressed air, water and electrical services already costed in other parts of this handbook.

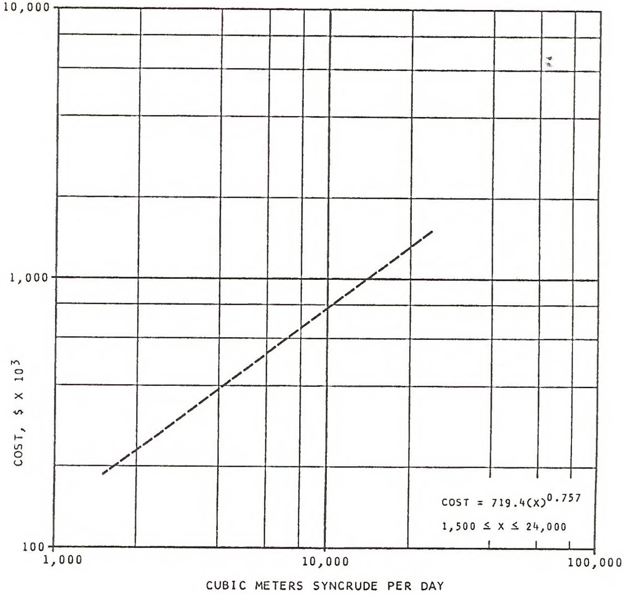


SCALE - LOGARITHMIC

10.1.3.5. ALARMS AND INSTRUMENTATION
CAPITAL COST

10.1.4. PAVING AND YARDWORK

The costs represented by this curve are for placement of asphalt paving, including grading, base and wearing courses; concrete sitework, including curbs, gutters and sidewalks; plus a limited amount of landscaping at the plant site. The costs are based on anticipated retorting production expressed in cubic meters of syncrude per day.



SCALE - LOGARITHMIC

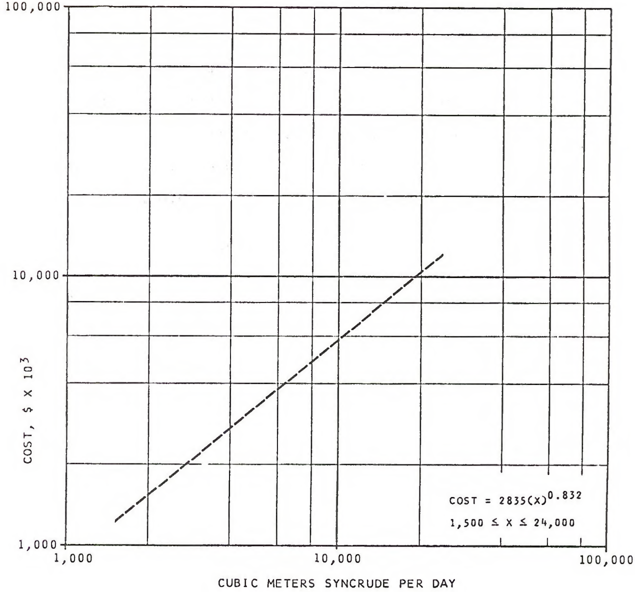
10.1.4. PAVING AND YARDWORK
CAPITAL COST

10.1.5. BUILDINGS

Plant buildings are those necessary for the operation of a commercial scale retorting and upgrading complex. Buildings related to security and fire protection have been included in Sections 10.1.6. and 10.1.7. Costs for furnishings are included with the capital costs.

The following functions are housed by the plant buildings and are exclusive of those provided for mining, as noted in other sections.

1. General administration offices for entire complex.
2. Plant control, operations and communication.
3. Process control and instrumentation.
4. Process control and development laboratories.
5. Employee services including cafeteria, first aid, auditorium and change areas.
6. Maintenance and repair operations.
7. Pump stations.

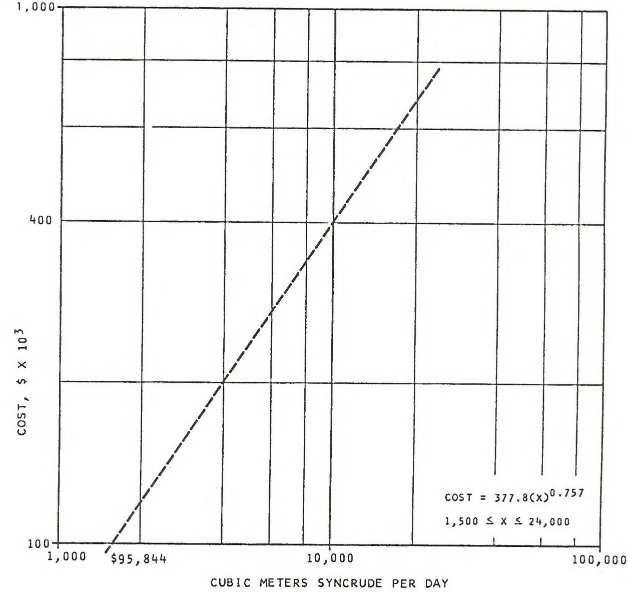


SCALE - LOGARITHMIC

10.1.5. BUILDINGS
CAPITAL COST

10.1.6. PLANT SECURITY

Plant security costs include all items typically related to plant security at a process plant operation of this type. Among these are security fencing, a central guard office with small guard stations at critical locations such as the plant entrances and special provisions for television monitors and separate communications systems.



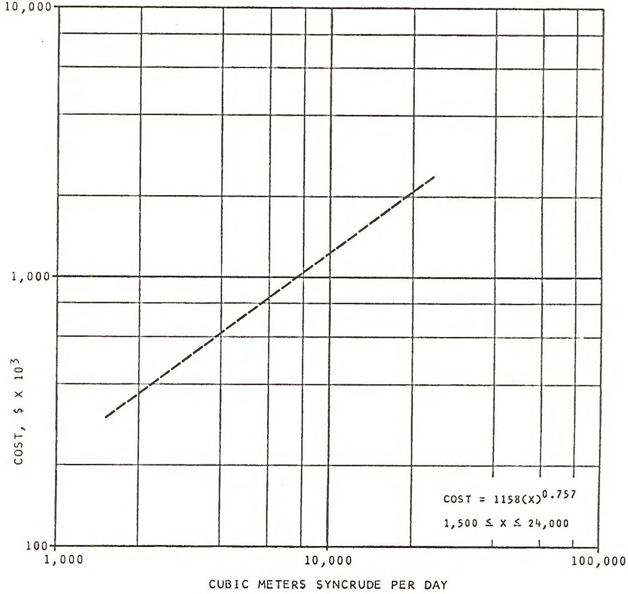
SCALE - LOGARITHMIC

10.1.6. PLANT SECURITY
CAPITAL COST

10.1.7. FIRE PROTECTION

Capital costs presented on the curve for fire protection are based on installing a system of the type required for the protection of retorting/upgrading facilities covered in this handbook.

Elements include provisions for a fire line system with hydrants, hose cabinets, reserve water tower with jockey pumps and firewater pumps. They also cover buildings and equipment required for the support of an in-plant fire department such as a fire station, fire alarm system, fire truck and foam wagon.



SCALE - LGOARITHMIC

10.1.7. FIRE PROTECTION
CAPITAL COST

10.1.8. TANKS

Tanks for storing liquid and gaseous materials at the retorting/upgrading plant site provide these necessary functions:

1. Storage of fuels required for mining, retorting, upgrading and general plant operations.

2. Surge storage for initial, intermediate and end products from retorting and upgrading processes in order to maintain continuing operations in one part of the plant complex while another is shut down for overhaul or repair work.

3. Storage of products produced by retorting and upgrading prior to further processing and/or shipment.

This curve provides for the related piping and pump installations together with the construction of auxiliary storage dikes at areas where flammable materials are stored. The costs shown on the curve include the following categories:

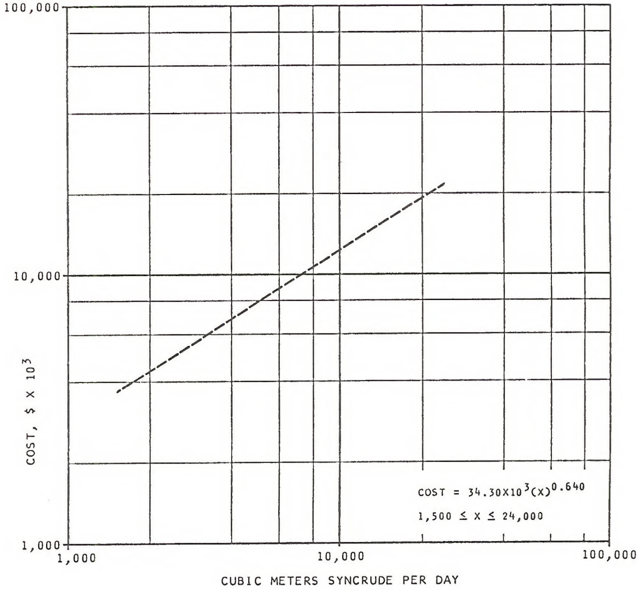
1. Fuel storage for plant operations

2. Product shale oil storage

3. Feed for upgrading processes

4. Upgrade product storage

5. Plant and process water storage



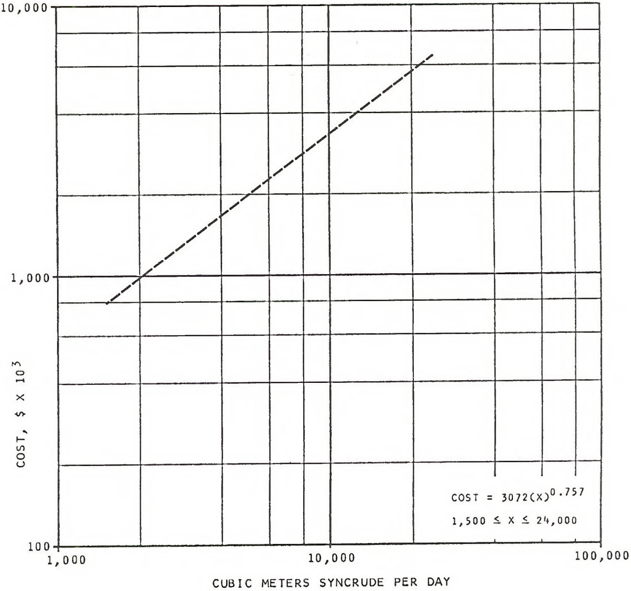
SCALE - LOGARITHMIC

10.1.8. TANKS
CAPITAL COST

10.1.9. SITE RESTORATION

The costs for this item have been developed to provide a capital reserve for meeting the requirement that the site be restored to "usable and productive" condition upon the termination of operations.

Allowances have been included in the total costs shown on the following cost curve for demolishing and removing or burying all paved and concrete areas including streets, retort, refinery, and tank and building footings, as well as overhead utilities. Salvage value has been considered and are offset by the removal costs. A provision has also been included for site regrading as well as revegetation.

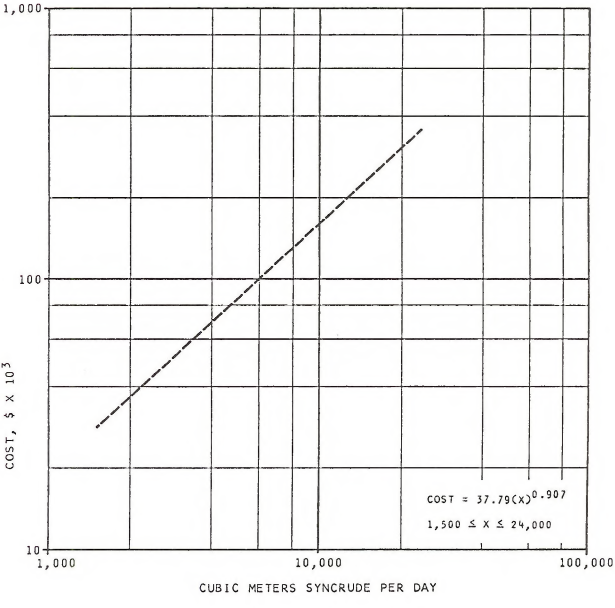


SCALE - LOGARITHMIC

10.1.9. SITE RESTORATION
CAPITAL COST

10.1.10. ADMINISTRATIVE EQUIPMENT

Administrative equipment consists of equipment used by management, engineering, safety, security and fire control personnel. The curve is for the initial purchase of equipment and is based on the daily production of the retorting/upgrading complex.



SCALE - LOGARITHMIC

10.1.10. ADMINISTRATIVE EQUIPMENT
CAPITAL COST

10.2. OPERATING COSTS

The operating costs in this section include the non-direct labor, administrative expenses and use of vehicles by the administrative personnel. Supervisors, engineers, and technical personnel that are unique to an element of the oil shale complex are included in the appropriate section. Costs for administrative functions that are common to the complex are included in this section.

Adjustment for escalation in the operating costs of facilities may be made by application of the cost index for "Refineries (Operation) shown in Section 2.3., Item 3.

10.2.1. GENERAL EXPENSES

General expenses are considered as those costs which are incurred by managerial, technical and administrative operations. Costs presented on the following curves are limited to direct operation requirements. Marketing, home office and other corporate expenses are not included. Operating costs can be determined by selecting the daily production of syncrude in cubic meters and reading the cost per day directly from the appropriate cost curve.

10.2.1.1. ADMINISTRATIVE SALARIES

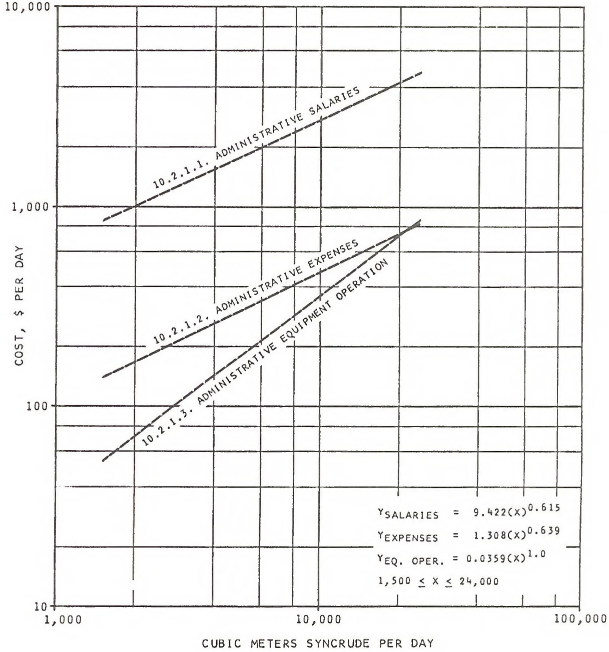
Administrative salary costs are for management, technical and other administrative personnel. Included in this grouping are the plant and assistant plant managers, shift superintendents, clerical staff, technical services group, safety, security, fire prevention and general maintenance top level supervision.

10.2.1.2. ADMINISTRATIVE EXPENSES

Administrative purchases covers office, engineering, safety and first aid supplies and expenses, such as communications, travel, miscellaneous fees, dues, donations, computer services, etc.

10.2.1.3. ADMINISTRATIVE EQUIPMENT OPERATION

Administrative equipment operating costs include operation of passenger cars, ambulances, fire and chemical trucks, and pickup and flat bed trucks used by the above described administrative personnel. These costs include tires, fuel, lubrication and repair parts.

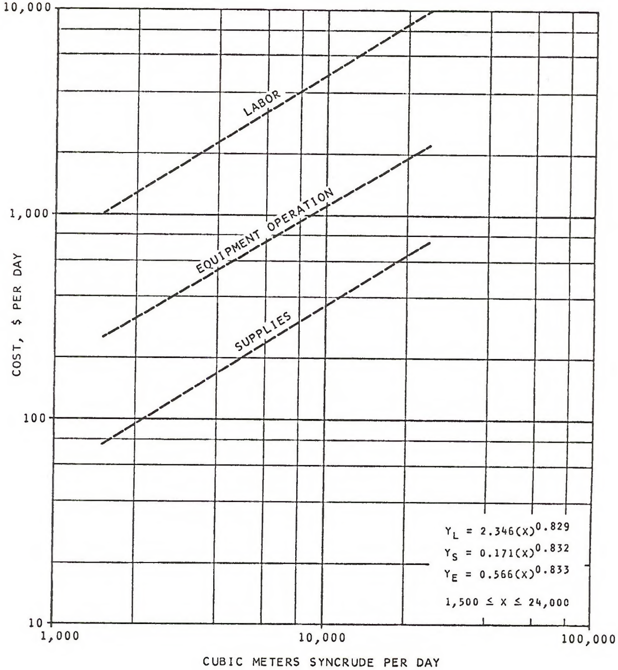


SCALE - LOGARITHMIC

10.2.1. GENERAL EXPENSE
OPERATING COST

10.2.2. FACILITIES OPERATING COSTS

Facilities operating costs are those costs related to maintenance and repair of the support facilities described in the capital costs portion of this section. Building repairs, roads and parking areas maintenance and general housekeeping are included in this item.



SCALE - LOGARITHMIC

10.2.2. FACILITIES OPERATING COSTS

11. SPENT SHALE DISPOSAL

The disposal of spent shale from the above ground retorts constitute a significant cost item. Disposal of the spent shale is considered to be by surface spreading or by returning the material to the mined out areas.

The surface disposal consists of moving the spent shale to a distribution point by belt conveyors. The material is then transported by truck to the dump area, spread and compacted. The final shale surfaces are revegetated to provide permanent stability.

The underground disposal system used in this handbook is a piped slurry system. The system consists of crushing the spent shale, transporting and placing by a slurry line, and returning the decant water to the surface to provide a closed circuit. It cannot be stated with absolute certainty that the underground openings provided by the mining will provide sufficient volume in all cases to place 100% of the spent shale. The amount of material removed from the oil shale plus the bulking and expansion characteristics of the material will determine the volume required for disposal. For use of this handbook it is assumed that the oil shale has the properties that will allow complete disposal of the spent shale underground should this option be selected.

For method to determine spent shale quantity, see Section 4.

11.1. SURFACE DISPOSAL

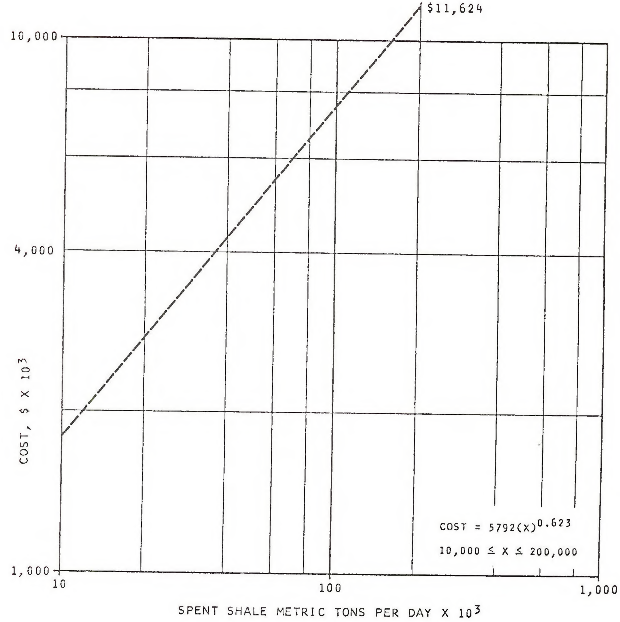
11.1.1. CAPITAL COSTS

The capital costs for the surface spent shale consist of the acquisition of equipment for the hauling and placement of the spent shale and the construction of dams to contain runoff from the spent shale or to impound surface runoff upstream from the disposal area. Transportation of the spent shale from the retort is by conveyor. I is necessary to determine the distance and profile from the retort to a central distribution point. The conveyor capital costs may then be obtained from Section 4.1.3.3.

Site preparation for the spent shale disposal area will consist of clearing the area and excavating and stockpiling topsoil for later use. The cost will depend upon the area cleared and the amount of topsoil excavated. Section 5.1.1.1. may be used to obtain the clearing cost and Section 5.1.1.2. for the topsoil excavation cost.

11.1.1.1. HAUL AND PLACEMENT EQUIPMENT

Capital costs for equipment to place spent shale in compacted fills on the surface consist of surge bins, motor grader, dozers, trucks, compactors, water trucks, grease trucks and pickups and includes the cost of constructing power and water lines from the processing plant to the disposal area.



$\text{COST} = 5792(X)^{0.623}$

$10{,}000 \leq X \leq 200{,}000$

SCALE - LOGARITHMIC

11.1.1.1. HAUL AND PLACEMENT EQUIPMENT CAPITAL COST

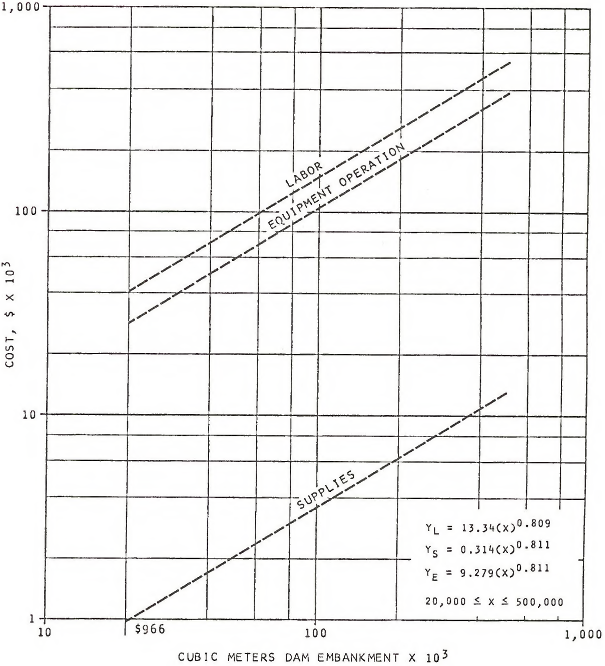
11.1.1.2. DRAINAGE CONTROL DAMS

To prevent erosion and contamination of runoff water, control dams will be required in canyons below the areas where spent shale is being placed. These dams will be constructed of local materials obtained from other construction on the surface or from underground waste material. The curve is based on dams of varying size and is meant to give the user a base for calculating the cost of a suitable small size dam.

Where it is necessary to purchase equipment due to this work being scheduled prior to the purchase of the haul and placement equipment (Section 11.1.1.2.), or have a subcontractor perform the work, multiply the equipment operation value by the following applicable factor in order to obtain the total value of equipment expense for ownership and operation:

Shifts per Day	1	2	3
Factor	2.05	1.79	1.70

If a subcontractor is used, multiply labor by 1.50, supplies by 1.20, and equipment expense by 1.20 to compensate for subcontractor's markup.



SCALE - LOGARITHMIC

11.1.1.2. DRAINAGE CONTROL DAMS
CAPITAL COST

11.1.2. OPERATING COSTS

Operating costs for surface disposal of the spent shale covers site preparation and topsoil stock piling; hauling, spreading and compacting the spent shale; revegetation on the spent shale surfaces. Operating costs of the conveyor to move the spent shale from the retorts to the distribution may be obtained from Section 4.2.2.2.

11.1.2.1. HAUL AND PLACEMENT

The spent shale that has been transported to disposal area by conveyor is temporarily stored in surge bins. Trucks of 150 ton capacity draw from the bins and haul to placement areas in close proximity to bins. Large dozers are used to spread the material and it is compacted by machine with water applied from tank trucks. A small crew with a motor grader handles storm drain channels, ditches and slopes.

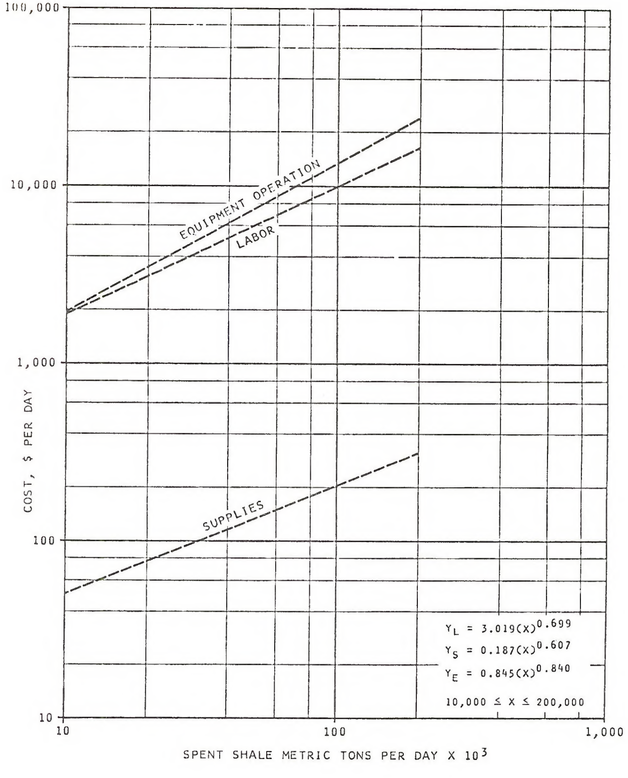
11.1.2.2. REVEGETATION

The cost of revegetation has been developed on the basis of spreading 15 centimeters of topsoil, planting grasses at the rate of 5.6 kilograms per hectare, spreading fertilizer at the rate of 450 kilograms per hectare the first year, 135 kilograms per hectare the following two years. Irrigation consists of installing a sprinkler system and applying water at the rate of 3,800 cubic meters per hectare the first year, 2,000 cubic meters per hectare the second year and 2,000 cubic meters per hectare the third year. Shrubs are also included in planting at the rate of 5.0 kilograms per hectare.

The cost of revegetation has been developed on the basis of spreading topsoil; planting grasses, shrubs and trees; providing an irrigation system; fertilizing and irrigating for three years. The costs per hectare are as follows:

Topsoil	$4,374
Water	1,056
Planting and Fertilizer	2,570

Total Cost per Hectare	$8,000



SCALE - LOGARITHMIC

11.1.2.1. HAUL AND PLACEMENT
OPERATING COST

11.2. UNDERGROUND DISPOSAL

The crushing plant for underground disposal contains a single deck screen ahead of each crusher so as to efficiently crush the processed shale. The product from the screens and the crushers passes directly into the water flowing to the slurry pump intakes. The crushing plant reduces the spent shale to minus 0.2cm in size to produce a pumpable slurry. Crushing costs are covered in Section 6.

11.2.1. CAPITAL COSTS

The capital costs for the underground disposal of spent shale consist of the slurry pumps and pipes to transport the slurry to the backfill area and pumps and pipes to return the decant water to the mixing area.

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11.2.1.1. PUMPS AND PIPING

Makeup water to produce a pumpable slurry will be provided by sour retort water, mine discharge water and slurry decant water. Concentration of solids by weight will be approximately 48% and due to the close proximity of shafts or declines, the surface pumps will be of a high volume, low head design. Pressure reducing devices will be required to hold the pressures down to a workable value at the discharge point.

The curve includes the cost of pumps, valves, pressure reducers, check valves and main system piping for the pumping of slurry into the mine and for the pumping of decant water back to the surface. Delivered equipment cost is 86% of total, installation 10% and construction material 4%. The curve covers pumping down a shaft of 300 meters and horizontally for a distance of 1500 meters. The total pumping head is 30 meters for a slurry containing 48% solids with a specific gravity of 1.38.

For each 100 meters of increase or decrease in horizontal pipe line, adjust curve value by ± 3%. For 500 meters or less of pipe line, use the value for 500 meters. For each 100 meters of increase or decrease of vertical shaft, adjust curve values by ± 4% to cover changes in required pumping and/or pressure reducing equipment and equipment installation. For vertical shafts 100 meters or less, use value for 100 meters.

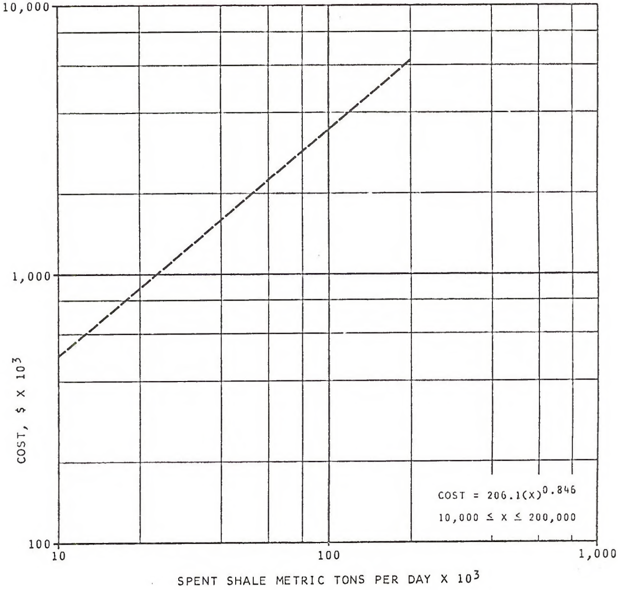
Example:

Shaft is 400 meters
Horizontal run is 1100 meters.
Spent shale = 25,596 metric tons per day
From curve, cost = $1,105,075 per day

Horizontal Adjustment:
$[(1100-1500)/100](.03)+1 = 0.880$

Vertical Adjustment:
$[(400-300)/100](.04)+1 = 1.040$

Capital Cost:
$1,105,075(0.880)(1.040) = 1,011\times10^3$



SCALE - LOGARITHMIC

11.2.1.1. PUMPS AND PIPING
CAPITAL COST

11.2.2. OPERATING COSTS

The operating costs for underground disposal include labor, supplies and equipment operation for pumping and panel preparation. Electric power is included in the operating costs.

11.2.2.1. PUMPING SLURRY

The spent shale slurry is pumped to the shaft collars and on to the disposal areas underground where the placement crews handle the distribution and movement of pipes from one location to another. This curve covers only the pumping operation.

The curve covers pumping down a shaft of 300 meters and horizontally for a distance of 1500 meters. The total pumping head is 30 meters for a slurry containing 48% solids with a specific gravity of 1.38.

The supply curve consists of electrical power only. For each 100 meter increase or decrease in horizontal pumping distance the supply cost is to be adjusted by ± 7%. For horizontal pumping distance 500 meters or less, use value for 500 meters.

Example:

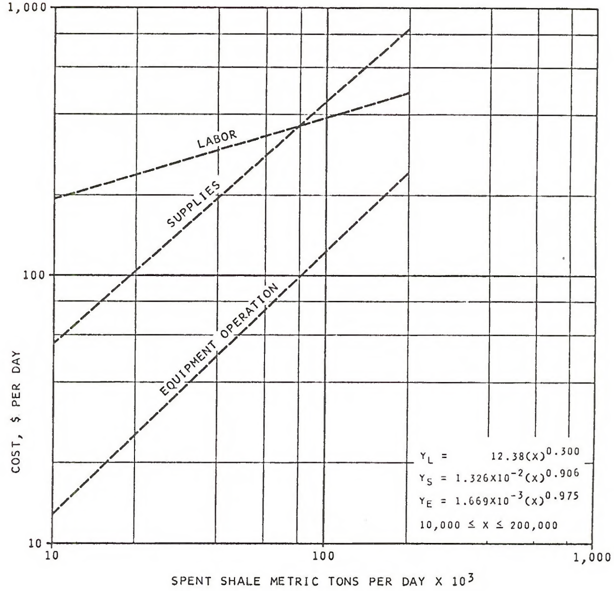
Shaft depth is 400 meters
Horizontal run is 1100 meters
Spent shale quantity is 25,596 metric tons per day
Supplies cost from curve = $131 per day

No vertical adjustment for shaft depth

Horizontal Adjustment:
[(1100-1500)/100](.07)+1 = 0.72C

Supply cost = 131(0.720) = $94 per day

For escalation of equipment operation, cost is distributed repair parts 90% and lubrication 10%.



SCALE - LOGARITHMIC

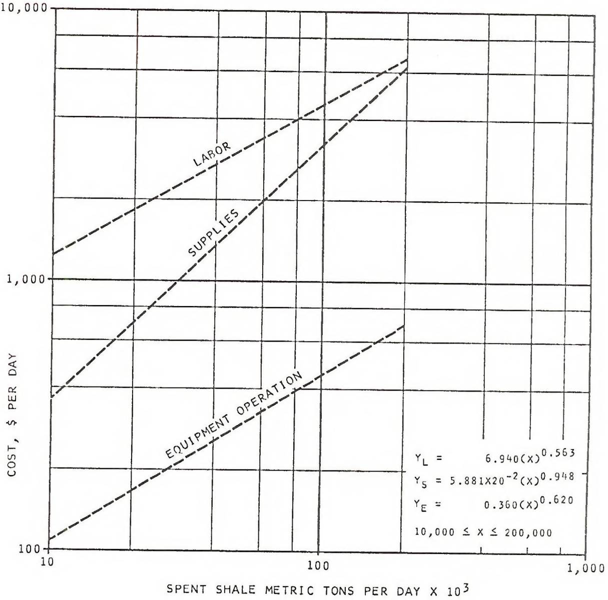
11.2.2.1. PUMPING SLURRY
OPERATING COST

11.2.2.2. PANEL PREPARATION

The crews installing the backfill bulkheads also handle the distribution piping in the panels, the movement of the main feeder piping from one panel to another and sump installation for pick up of decant water.

Supplies consist of construction materials such as timbers, caulking and sealing material for the bulkheads at the panel entrances.

Equipment consists of flatbed trucks, forklifts and utility vehicles. The equipment operation is distributed 15% tires, 43% fuel and lube and 42% repair parts.



SCALE - LOGARITHMIC

11.2.2.2. PANEL PREPARATION UNDERGROUND DISPOSAL OPERATING COST

11.2.2.3. PUMPING DECANT WATER

Decant water will be pumped back to the surface to be recirculated. The curve is based on pumping the decant water a horizontal distance of 1500 meters with a vertical lift of 300 meters for a total head of 320 meters at a specific gravity of 1.05.

The supply curve consists only of electrical power. For each 500 meter horizontal increase or decrease of the pumping lines, the supply curve is to be adjusted by ±1%. For lines 500 meters or less, use value for 500 meters. For each 100 meter vertical lift change, the supply curve is to be adjusted by ± 30%. For lift 100 meters or less, use value for 100 meters.

Example:

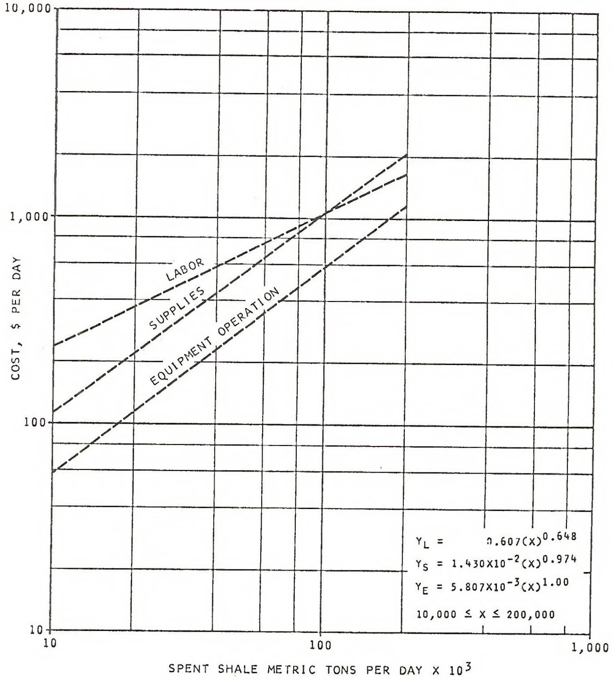
Shaft depth is 400 meters
Horizontal run is 1500 meters
Spent shale = 25,596 metric tons per day
From cost curve:
Supplies = 281 per day

Horizontal Adjustment:
[(1,100-1,500)/500](0.01)+1 = 0.992

Vertical Adjustment:
[(400-300)/100](0.30)+1 = 1.300

Adjusted Supplies Cost:
281(.992)(1.300) = $362

The equipment operating cost consists of 90% repair parts and 10% lube.



SCALE - LOGARITHMIC

11.2.2.3. PUMPING DECANT WATER
OPERATING COST

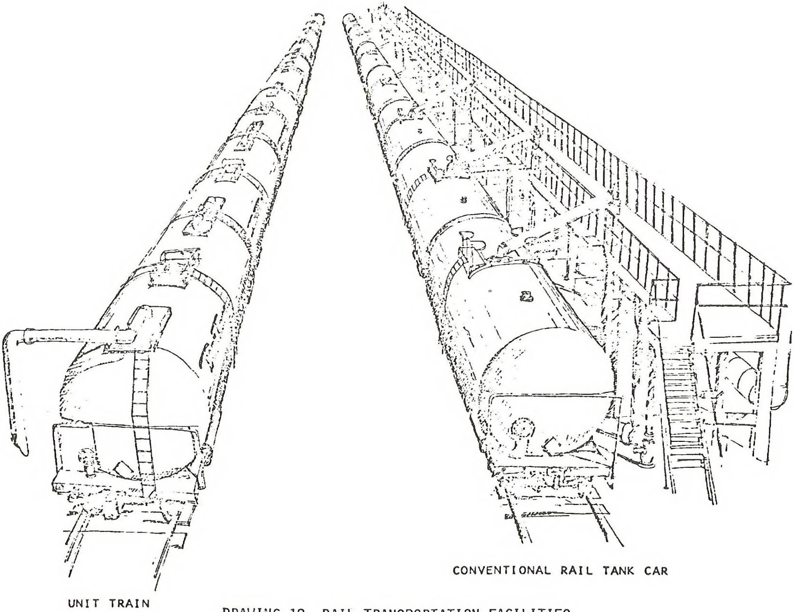
12. TRANSPORTATION

The estimating system for syncrude transportation is based on the use of either rail or pipeline. For purposes of this handbook, all reference to transportation of syncrude applies to products resulting from upgrading. The quantity of material to be transported is dependent on the slate selected for the upgrading process and the market products resulting from that slate. Table 9. may be used to determine the amount of material to be transported.

Rail transportation consists of pumping the syncrude from a plant site via a suitable pipeline to a rail terminal. Here it is loaded into one or more "strings" of unit trains, (see Drawing 12). and moved to the consumer over existing railways.

In pipeline transportation syncrude is pumped from the plant site through a longer pipeline to an existing pump station. This pump station serves as the transfer point for moving the syncrude to the consumer via an existing common carrier pipeline. A constant diameter pipe has been used for developing the cost in the various items in this section, therefore, there will be no economy of scale apparent with increased volumes in the pipeline.

In using either mode, it must be noted that neither capital nor operating costs for transportation include any of the special costs which may be required by local or federal agencies. These special costs include predevelopment costs and environmental studies (see Section 3.), land acquisition fees and rents, and special permits and taxes.


CONVENTIONAL RAIL TANK CAR
UNIT TRAIN

DRAWING 12. RAIL TRANSPORTATION FACILITIES

12.1. CAPITAL COSTS

Capital costs are based on the specified movement of a given volume of syncrude expressed in cubic meters per day. The costs represent the investment in facilities and equipment required between the point of production and point of further shipment.

12.1.1. PIPELINE FROM PLANT TO LOADING FACILITIES

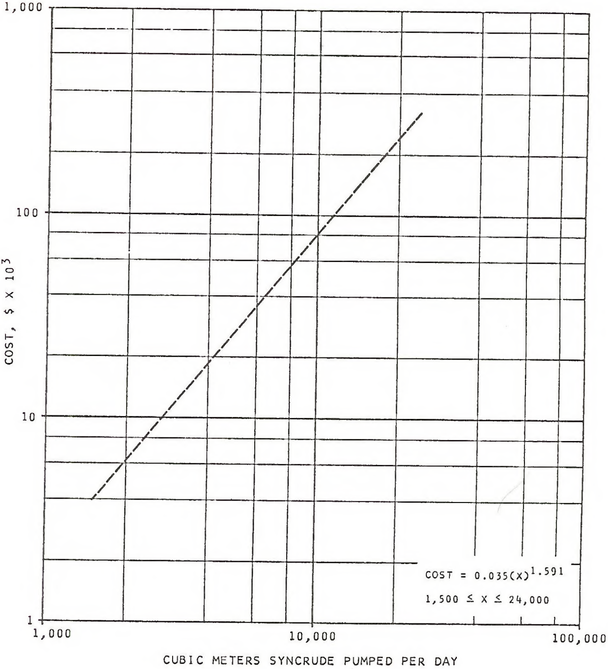
The pipeline and pumping facilities used as the basis for developing these cost figures was selected to be similar in construction to the pipeline described in Section 12.1.4., Long Distance Pipeline Facilities. The principal differences are reduced length, reduced pumping requirements and lack of river crossings.

Capital costs for the pipeline to the loading facilities are based on a 26 kilometer long welded steel pipeline, approximately 41 centimeter in diameter varying in thickness from approximately 0.67 centimeter to 1.33 centimeter designed to transport 7,950 cubic meters of syncrude. Due to the constant diameter and volume basis used for design, there will be no economy of scale for other volumes. The estimated cost of this pipeline is $3,380,000.

Capital costs for pumping facilities are obtained by selecting the production rate in cubic meters per day and reading the capital cost in dollars directly from the curve. This cost is then added to $3,380,000 to obtain the total capital cost.

The total capital cost may then be adjusted for the specific pipeline length in direct ratio to the 26 kilometer base pipeline.

For escalation use index from Section 2.3., Item 9., Construction Materials.



SCALE - LOGARITHMIC

12.1.1. PIPELINE FROM PLANT TO LOADING FACILITIES
PUMPING FACILITIES

CAPITAL COST

12.1.2. RAIL LOADING FACILITIES

These facilities consist of a terminal for the pipeline described in the preceding subsection and an installation for transferring syncrude to railroad trains made up of one or more 18-car "strings" of unit train railway tank cars. For further discussion of rail transportation facilities refer to Section 12.1.3.

Costs contain provision for such capital items as site development, storage tanks, pumping facilities, trackage, incidental piping and utilities as well as tank car loading platforms and related equipment.

The costs for unloading facilities have not been included in this handbook because typically, the syncrude will be unloaded by the consumer.

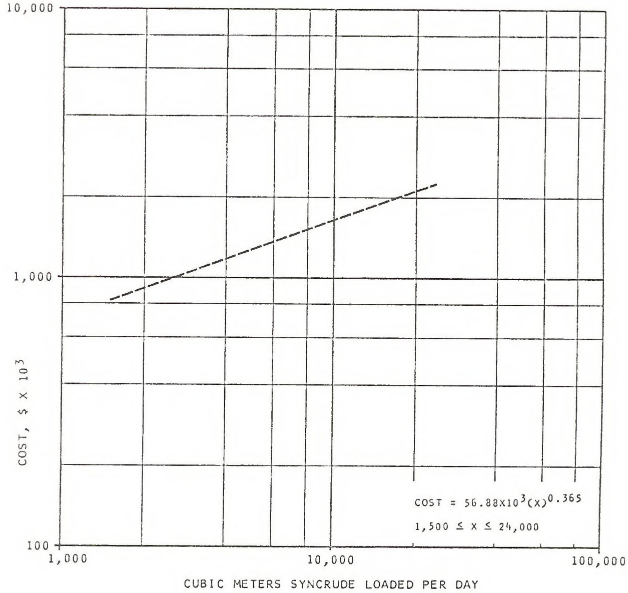
Typical unit train loading facilities can move crude petroleum oil or syncrude into an 18-car "string" of unit train tank cars at a rate of 7.6 cubic meters per minute or 3-1/2 hours loading time per "string". By adding allowances for positioning, hooking up and disconnecting the fill lines, and coupling the "string" of tank cars, a terminal cycle time of 4-1/2 hours per 18-car "string" is used.

This means if longer loading and train makeup times were allowable, or if syncrude were to be moved in relatively short length trains, a single loading facility could meet the loading requirements for up to a shipping rate of 7,950 cubic meters per day, by providing five daily tank car loadings of approximately 1,590 cubic meters each.

Because of the desirability of moving syncrude while it is relatively warm, and the economies obtained from the shorter terminal times, it is considered advisable to increase the number of loading tracks and platforms. If the ratio is one unit train for each 1,590 cubic meters increment of shipping up to 7,950 cubic meters per day, there is developed a capacity to move an entire 5 "string" unit-train of 90 tank cars through the terminal in less than 5 hours. At this stage of development, further expansion of the installation's car loading facilities would not be required unless it became necessary to move more than 40,000 cubic meters per day.

With these data, the capital cost of railroad tank car loading facilities can be calculated from the curve shown on Figure 12.1.2. after determining the quantity of syncrude to be moved by rail.

For escalation use index from Section 2.3., Item 9., Materials.



SCALE - LOGARITHMIC

12.1.2. RAIL LOADING FACILITIES
CAPITAL COST

12.1.3. RAIL TRANSPORTATION EQUIPMENT

The capital costs presented in this section are related to the purchase of one or more "strings" or modules consisting of 18 railway tank cars specially constructed for "unit-train" service in moving syncrude. For escalation use index from Section 2.3., Item 4., Equipment. If cars are to be leased rather than purchased the capital costs in this section do not apply, therefore, refer to Section 12.2.3., Rail Transportation.

Each of the tank cars in the "string" has a capacity of roughly 88 cubic meters and is insulated to keep the hot syncrude warm for a considerable length of time. The cars are also outfitted with a special rapid flow piping arrangement (see Drawing 12.) which allows the entire "string", holding approximately 1,590 cubic meters of syncrude, to be loaded or discharged quickly through a single contact point. It also makes it possible for the entire module of up to five "strings" to be moved as a unit. In addition to an obvious reduction in the time and labor required for loading and unloading operations, further savings are also obtained in the form of lower transportation rates because of the advantages to the carrier in handling a single ready-made large haul.

The capital cost of each unit train tank car is approximately $50,000. With an industry recommended allowance of 10% for spare cars, the cost of an 18-car "string" is $990,000.

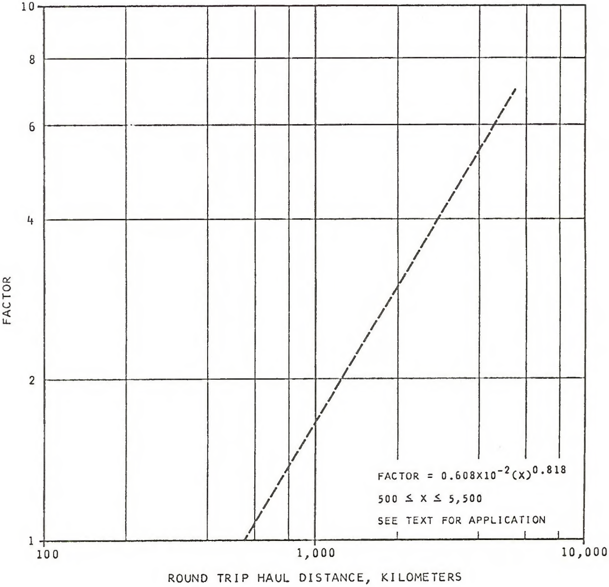
Since the capacity of a "string" is assumed to be equal to the daily output of one 1,590 cubic meter increment of retorting/upgrading production, the minimum capital cost for rail transportation facilities corresponds to the proposed number of such production increments. In addition the number of "strings" of cars required for a given set of haul conditions must be determined. This number is affected by the fixed elements (turnaround times at rail terminals) and variable elements (hauling time) of rail haul.

Figure 12.1.3. is used to determine the number of trains needed for operating over a given haul distance. The number of "strings" and multiplier, if not integer numbers, must be rounded to the next higher integer numbers. The cost of rail facilities for a retorting/upgrading facility can thus be determined as the product of that multiplier times the cost of the number of strings required to haul the daily output.

For example, to transport 5,132 cubic meters of syncrude per day with a round trip distance of 3,000 kilometers:

Number of "strings" = 5,132/1,590 = 3.228
From Figure 12.1.3., Factor = 4.248

Therefore:
Cost = 990,000(3.228)(4.248) = $13,575x10^3



SCALE - LOGARITHMIC

12.1.3. RAIL TRANSPORTATION EQUIPMENT
TRAIN DETERMINATION
FOR

CAPITAL COST

12.1.4. LONG DISTANCE PIPELINE FACILITIES

There being no average syncrude pipeline, for this handbook, a pipeline proposed as a connection between the Parachute Creek, Colorado operations and an existing commercial pipeline at Lisbon Valley, Utah, was determined to be representative of the basic requirements for long distance pipeline transportation facilities. This pipeline system is composed of a 312 kilometer long welded, coated and wrapped steel pipeline approximately 41 centimeter in diameter and varying in thickness between approximately 0.67 centimeter and 1.33 centimeter designed to transport 7,950 cubic meters of syncrude daily. Due to the constant pipe diameter there will not be an economy of scale for other volumes. The pipeline is designed to be installed 2 meters underground in a 6 to 8 meter wide utility corridor between the points of production and its connection to an existing pipeline. With a booster pump station located south of Moab, Utah, this pipeline can transport from 1,590 to 24,000 cubic meters of syncrude daily.

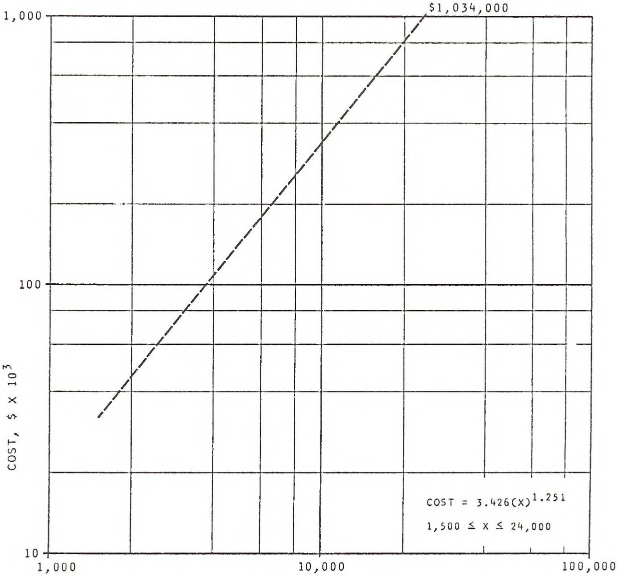
In addition to meeting government and petroleum industry requirements for pipeline design and construction, special provisions are to be taken in its alignment, construction and operation to minimize actual and potential damage to the environment of the traversed areas.

In estimating the capital costs for long distance pipeline facilities, the sum of the capital costs for the pipeline and transfer facilities plus the related pumping costs must be used. These may be developed as follows:

1. Capital costs for the long distance pipeline and transfer facility outlined above include furnishing and installing the line complete with provision for clearing and site restoration; erosion control; cofferdams and special precautions at river crossings; emergency provisions for oil spill contingencies including special shut-off valves; cathodic protection; remote control and monitoring systems and also storage facilities at Lisbon, Valley. The estimated cost for this portion of the long distance pipeline facilities is $34,625,000.

2. To the pipeline cost must be added the capital costs for pumping facilities as shown on Figure 12.1.4. This includes provision for a complete initial pump station at Parachute Creek and transfer pump station at Lisbon Valley. As pumping volume increases, this curve reflects the increases in cost for larger pumping capacity requirements at these two locations plus the necessity for an additional (booster) station near Moab, Utah. Therefore, capital costs for the requisite pumping facilities are obtained by determining the syncrude transportation volume in cubic meters per day and reading the capital cost in dollars directly from the curve.

Text continued on page 268.



SCALE - LOGARITHMIC

12.1.4. LONG DISTANCE PIPELINE FACILITIES
PUMPING FACILITIES

CAPITAL COST

The total cost may be adjusted for different lengths of similar pipeline in a direct ratio to the 312 kilometer base pipe line.

For escalation use index from Section 2.3., Item 9., Materials.

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12.2. OPERATING COSTS

Operating costs for syncrude transportation are based on the planned production and subsequent daily movement of a given quantity of syncrude through one or more of the two previously discussed modes of transportation.

In calculating the operating costs for moving a specific volume of syncrude from the retorting/upgrading complex to a given destination and utilizing rail transportation facilities (unit-trains), the sum of the appropriate operating costs for each facility that is involved must be developed.

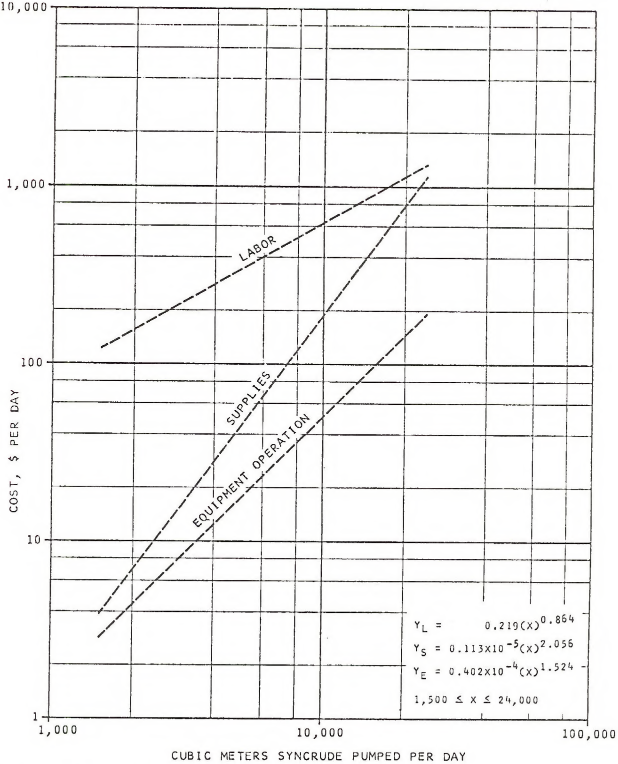
12.2.1. PIPELINE FROM PLANT TO LOADING FACILITIES

Operating costs for this element of transportation are the sum of the daily operating costs for the pipeline and for the appropriate pumping facilities. They are to be developed as follows:

1. Operating costs for the pipeline only are based on the previously described 26 kilometer steel pipeline. The daily cost for this pipeline is $515 distributed 64% labor, 14% supplies and 22% equipment operation. Supplies consist of industrial materials. Equipment operation is distributed 66% fuel and lube and 34% repair parts.

2. Operating costs for the pumping facilities are obtained by selecting the production rate in cubic meters per day and reading the cost directly from the curve provided for this purpose on Figure 12.2.1. Supplies are distributed 90% power and 10% industrial materials. Equipment operation is distributed 10% lube and 90% repair parts.

The costs obtained from the curve can be adjusted for the specific pipeline length as a direct ratio of the 26 kilometer base.



SCALE - LOGARITHMIC

12.2.1. PIPELINE FROM PLANT TO LOADING FACILITIES
PUMP FACILITIES

OPERATING COST

12.2.2. RAIL LOADING FACILITIES

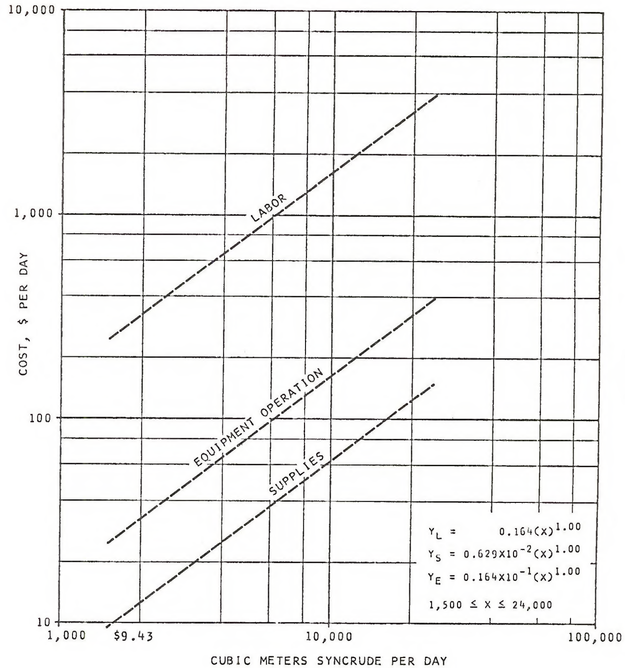
The daily operating expenses for these facilities are presented on Figure 12.2.2.

The labor costs recognize that with a unit-train installation, loading operations require only a limited portion of the entire work day. However, it is considered that when not involved in this work, the labor force will be occupied in other related activities such as gauging and sampling storage tanks, plant repairs and other maintenance work.

Likewise, supplies and equipment operating costs reflect the daily requirements for both terminal and loading facilities.

Supplies are distributed 42% power and 58% industrial materials.

Equipment operation is distributed 66% fuel and lube and 34% repair parts.



SCALE - LOGARITHMIC

12.2.2. RAIL LOADING FACILITIES
OPERATING COST

12.2.3. RAIL TRANSPORTATION

Operating costs for rail transportation facilities are the sum of equipment operating costs and rail charges for round trip movement of the tank cars between supplier and consumer.

In calculating these particular costs, the user must realized that they are affected by both the volume of syncrude to be moved and the haul distance or daily movement in terms of cubic meter kilometers and not cubic meters alone.

For this handbook, these costs have been presented on the basis of industry practice with unit-train use costs expressed as lease rates and railway charges quoted for the average weight of loaded and empty unit-trains.

Using the number of "strings" and distance multiplier the daily equipment operating cost can be obtained by multiplying the product of the number of "strings" and the distance multiplier by $455. This cost does not apply if cars are purchased.

Rail charges are based on an estimated average weight of 1,355 metric tons (2,098 metric tons full, 612 metric tons empty) for an 18-car "string" and apply to leased or purchased facilities. At a typical charge of $0.0043 per metric ton kilometer ($0.01 per ton mile), the rail charges are $5.83 per kilometer per "string".

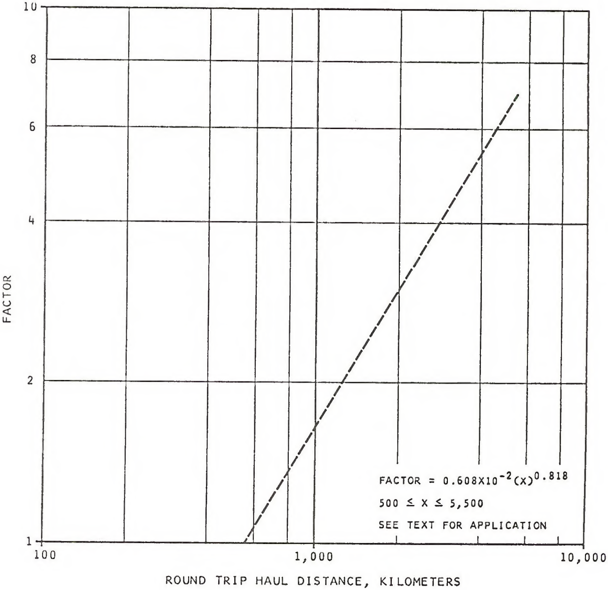
For example, to transport 5,132 cubic meters of syncrude per day with a round trip distance of 3,000 kilometers using leased or purchased cars:

Number of "strings" = 5,132/1,590 = 3.228
From Figure 12.2.3., Factor = 4.248

Therefore:

For leased cars:
Equipment operating cost = 455(3.228)(4.248) = $6,239
Rail charges = 3,000(3.228)(5.83) = $56,458
Total operating cost = (6,239+56,458) = $62,697

For purchased (owned) cars:
Total operating cost = Rail charges = $56,458



FACTOR = $0.608 \times 10^{-2} (X)^{0.818}$

$500 \leq X \leq 5{,}500$

SEE TEXT FOR APPLICATION

SCALE - LOGARITHMIC

12.2.3. RAIL TRANSPORTATION
TRAIN DETERMINATION
FOR

OPERATING COST

12.2.4. LONG DISTANCE PIPELINE FACILITIES

Operating costs for long distance pipeline facilities are expressed as the sum of (1) the daily operating costs for the long distance pipeline and (2) the necessary pumping operations.

1. pipeline operating costs are based on the previously described pipeline in Section 12.1.4. The daily cost for this portion of the long distance pipeline facilities is $2,430 distributed 58% to labor, 13% to supplies and 29% to equipment operation. Supplies consist of industrial materials. Equipment operation is distributed 66% to fuel and lube and 34% to repair parts.

2. the operating cost of the pipeline and the costs for the related pumping operations are obtained by selecting the pumping rate in cubic meters per day and reading the appropriate labor, supplies, or equipment operating costs directly from Figure 12.2.4. Supplies are distributed 90% power and 10% industrial materials. Equipment operation is distributed 10% lube and 90% to repair parts.

The total cost obtained may be adjusted for a specific pipeline length in direct ratio to the 312 kilometer base pipeline.

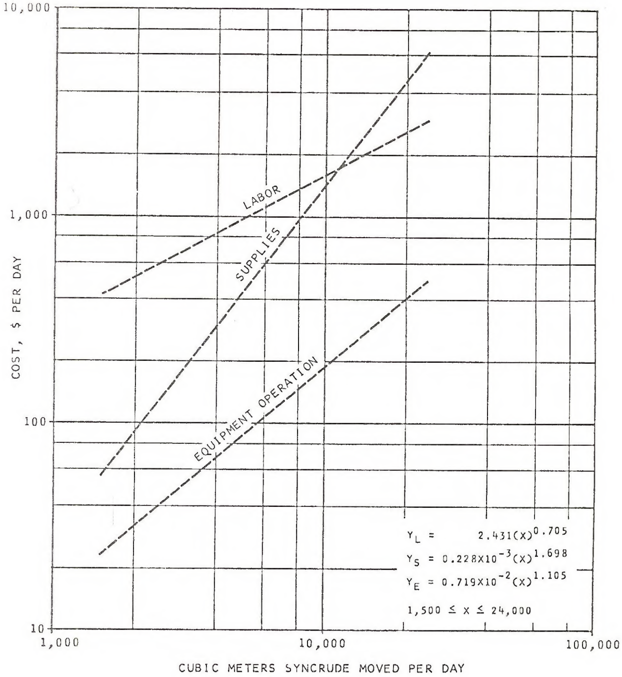
Fxample of operating cost of a 300 kilometer pipeline moving 10,000 cubic meters per day:

1. Labor = 2430(.58) = $1,409
   Supplies = 2430(.13) = $316
   Equipment Operation = 2430(.29) = $705

2. Labor = $1,606
   Supplies = $1,412
   Equipment Operation = $189

Total cost:
   Labor = 1409+1606 = $3,015
   Supplies = 316+1412 = $1,728
   Equipment Operation = 705+ 189 = $894

Total cost adjusted for pipeline length:
   (300/312)(3015+1728+894) = $5,420



SCALE - LOGARITHMIC

12.2.4. LONG DISTANCE PIPELINE FACILITIES
PUMPING FACILITIES

OPERATING COST

13. SUPPLEMENTAL COSTS

13.1. CAPITAL COSTS

13.1.1. ENGINEERING AND CONSTRUCTION MANAGEMENT FEES

The correlation between capital cost and fees for engineering and/or construction management services are based on a variable percentage of the estimated constructed cost. The factors below for design and engineering services are based on data in the ASCE - Manuals and Reports on Engineering Practice - No. 45 and the construction management factors are based on the current practices of several firms engaged in the management of mining and refinery projects.

The capital cost used in the equations below should already be appropriately adjusted for escalation, therefore, do not escalate fee.

The factors for determining fees are as follows:

For Section 4., Underground Mining, Section 8., Modified In Situ Retorting, and Section 12., Transportation:

$$\text{Engineering Fee} = 0.258(C)^{0.902}$$

$$\text{Construction Management Fee} = 0.085(C)^{0.948}$$

For Section 5., Open Pit Mining:

$$\text{Engineering Fee} = 0.206(C)^{0.902}$$

$$\text{Construction Management Fee} = 0.068(C)^{0.948}$$

For Section 6., Crushing, Section 7., Retorting and Auxiliary Processes, Section 9., Upgrading, Section 10., Facilities for Upgrading and Retorting, and Section 11., Spent Shale Disposal:

$$\text{Engineering Fee} = 0.347(C)^{0.896}$$

$$\text{Construction Management Fee} = 0.090(C)^{0.948}$$

Where:
C = Capital cost

13.1.2. WORKING CAPITAL

Working capital may be defined as those funds or sources of money required to meet payrolls, accounts payable such as everyday supplies and warehouse inventory, and to carry accounts receivable from sales of the products produced.

Working capital is estimated as that amount necessary for 60 days of operating and administrative cost, plus 10% reserve fund for contingencies.

Do not escalate this cost.

14. SAMPLE PROBLEM

The following problem is provided to illustrate the use of the handbook. A logical sequence is followed for the solution of the problem starting with exploratory drilling and tracing the development of the oil shale complex through mining, retorting, upgrading and transportation. The examples are not intended to represent a particular oil shale project or an efficient mix of components, but rather to show how some of the handbook curves, equations, factors and the user's judgement may be used in arriving at cost. A surface mine and an underground mine have been included in order to illustrate the use of the handbook with both mining methods.

Basic Problem Data:

Date:
    1977
Size of property:
    2,000 ha
Drill hole depth:
    450m
Drill hole spacing:
    1 hole / 50 ha
Grade of oil shale:
    0.130 m^3/t
Grade of Nahcolite:
    18%
Grade of Dawsonite:
    11%
Dewatering:
    25 m^3/minute
Depth of underground mine main level:
    400 m
Depth of access shaft:
    440 m
Depth of topsoil:
    0.2 m
Thickness of surface mine overburden:
    30 m
Thickness of surface mine oil shale:
    100 m
Syncrude output:
    4,770 m^3/day Counter Gravity, Indirect Heated with SGR Retort
Spent shale disposal method:
    Underground Slurry Pipeline
    Average 1100 m horizontal run
Upgrading slate:
    Standard slate from Table 9. for 4,770 m^3/d of syncrude, except residues to coking plant at 1,270 m^3/d.
Work period:
    Three shifts per day
    Seven day week
Transportation:
    30 km pipeline to railhead and
    1,500 km by rail to delivery point
    Use purchased cars

Cost Index Adjustment Factors

No.	Cost Index	1977 Value	Handbook Value*	Adjustment Factor
1.	Mining Labor	6.88	6.39	1.077
2.	Construction Labor	2265.6	2171.2	1.043
3.	Refineries (Operation)	228.2	209.0	1.092
4.	Equipment and Repair	213.7	199.8	1.070
5.	Iron and Steel	230.3	219.7	1.048
6.	Petroleum	308.1	276.2	1.115
7.	Refineries (Construction)	653.0	615.7	1.061
8.	Tires	171.5	157.1	1.092
9.	Construction Materials	237.7	203.0	1.171
10.	Industrial Materials**	195.1	182.6	1.068
11.	Transportation	197.1	183.6	1.074

* June 1976
** use for miscellaneous items

Power at $0.025/kw-h, therefore escalation factor = 1.000

The following notations are used in the calculations

C = Cost
CE = Cost of Equipment Operation
CL = Cost of Labor
CS = Cost of Supplies
F = Factor

All units used in the sample problem are in the metric system.

3. Predevelopment Capital Cost

3.1. Environmental Studies

$C = 2{,}000(270) = \$540x10^3$

3.2.1. Core Drilling & Logging

$C = 66{,}000(450/1000)(2000/50)(1.043) = \$1{,}239x10^3$

3.2.2. Assaying

$C = 3{,}600(450/1000)(2000/50)(1.043) = \$68x10^3$

Total Capital Cost Group 3.

3.1.	$ $54x10^3$
3.2.1.	$1{,}239x10^3$
3.2.2.	$68x10^3$

	$\$1{,}361x10^3$

4.1. Underground Mining Capital Cost

$\text{Mine production} = 4{,}770/\{0.130[1-.2(.18)]\} = 38{,}062$

Use 38,000 t/d

4.1.1.1. Mine Development

$\text{Days} = 38{,}000(1.25x10^{-3}) = 48 \text{ days}$

$\text{Tons} = .341(38{,}000)^{1.416} = 1{,}042x10^{3}$

$CL = 708{,}646(1.077) = \$763x10^{3}$

$CS = 469{,}308[1.068(.40+.08+.10)+1.048(.42)] = \$497x10^{3}$

$CE = 403{,}380[1.115(.36)+1.070(.20)+1.092(.44)] = \$442x10^{3}$

For Hoisting (4.2.4.1.) ton-meters per day = 38,000(400)= 15,200x10^{3} t-m/d

$CL = 1{,}417(48)(1.077) = \$73x10^{3}$

$CS = 2{,}353(48)[.75+.25(1.048)] = \$114x10^{3}$

$CE = 515(48)[1.115(.09)+1.070(.91)] = \$27x10^{3}$

$C = (763+497+442+73+114+27)x10^{3} = \$1{,}916x10^{3}$

4.1.1.2. Access Shaft

Ton-meters per day = 440(38,000) = 16,720x10^{3} t-m/d

$CL = 1{,}718{,}844(1.043) = \$1{,}793x10^{3}$

$CS = 1{,}476{,}131[1.171(.47)+1.070(.38)+1.068(.10)+1.048(.05)] = \$1{,}648x10^{3}$

$CE = 182{,}505[1.070(.42+.51)+1.115(.04)+1.092(.03)] = \$196x10^{3}$

$C = (1{,}793+1{,}648+196)x10^{3} = 3{,}637x10^{3}$

4.1.2.1.1. Shaft Ventilation

$CL = 2{,}431{,}054(400/300)(1.043) = \$3{,}381x10^{3}$

$CS = 2{,}092{,}627(400/300)[1.171(.53+.21)+1.068(.20)+1.048(.06)] = \$3{,}189x10^{3}$

$CE = 578{,}349(.624)(400/300)[1.115(.04)+1.070(.33+.63)] = \$516x10^{3}$

$C = (3{,}381+3{,}189+516) = \$7{,}086x10^{3}$

4.1.2.2. Surface Buildings

$C = (221{,}128+321{,}403+349{,}980)[1.043(.25)+1.171(.17)+1.070(.58)] = \$964x10^{3}$

4.1.3.1. Excavation Equipment

$C = 8{,}189{,}000[1.043(.09)+1.171(.02)+1.070(.89)] = \$8{,}759x10^{3}$

4.1.3.2. Hoisting Equipment

Ton-meters per day = 400(38,000) = 15,200,000 t-m/d

$C = 3{,}301{,}700[1.043(.15)+1.171(.10)+1.070(.75)] = \$3{,}553x10^{3}$

4.1.3.5. Mine Drainage & Dewatering

$C = 482{,}626\{1+[.7x10^{-3}(400-350)]\}[1.070(.76)+1.043(.15)+1.171(.09)] = \$537x10^{3}$

Total Capital Cost Group 4.1.

4.1.1.1.	$\$\ 1,916x10^{3}$
4.1.1.2.	$3,637x10^{3}$
4.1.2.1.1.	$7,086x10^{3}$
4.1.2.2.	$964x10^{3}$
4.1.3.1.	$8,759x10^{3}$
4.1.3.2.	$3,553x10^{3}$
4.1.3.5.	$537x10^{3}$
	$\$26,452x10^{3}$

4.2. Underground Mining Operating Cost

4.2.1. General Operations
CL = 5,472(1.077) = $5,893
CS = 4,028(1.068) = $4,302
CE = 250[1.070(.42)+1.092(.12)+1.115(.46)] = $273
C = (5,893+4,302+273) = $10,468

4.2.2.1. Ventilation System
Exponential = $0.875(400)^{0.056} = 1.224$
Depth F = $1.507(400)^{-0.066}(38{,}000)^{-1.239}(38{,}000)^{1.224} = .866$
C = 143(.866)[1.000(.94)+1.070(.03)+1.115(.03)] = $124

4.2.3.1. Mine Excavation
CL = 8,397(1.077) = $9,044
CS = 8,588[1.068(.59)+1.048(.41)] = $9,102
CE = 7,166[1.115(.38)+1.092(.30)+1.070(.32)] = $7,837
C = (9,044+9,102+7,837) = $25,983

4.2.4.1. Hoisting
Ton-meters per day = 400(38,000) = 15,200,000 t-m/d
CL = 1,417(1.077) = $1,526
CS = 2,353[1.000(.75)+1.048(25)] = $2,381
CE = 515[1.115(.09)+1.070(.91)] = $553
C = (1,526+2,381+553) = $4,460

4.2.4.4. Mine Dewatering
Head F = 1+[.0084(440-350)] = 1.756
CL = 583(1.756)(1.077) = $1,103
CS = 1,331(1.756)(1.000) = $2,337
CE = 362(1.756)[1.070(.90)+1.115(.10)] = $683
C = (1,103+2,337+683) = $4,123

4.2.5. Mine Services
CL = 2,409(1.077) = $2,594
CS = 1,335(1.068) = $1,426
CE = 793[1.092(.43)+1.115(.37)+1.070(.20)] = $869
C = (2,594+1,426+869) = $4,889

4.2.6.1. Administrative Salaries
CL = 1,894(1.25)(1.077) = $2,550

4.2.6.2. Administrative Expenses
CS = 323(1.068) = $345

4.2.6.3. Administrative Equipment Operation
CE = 198[1.092(.05)+1.115(.62)+1.070(.33)] = $218

Total Operating Cost Group 4.2.

4.2.1.	$10,468
4.2.2.1.	124
4.2.3.1.	25,983
4.2.4.1.	4,460
4.2.4.4.	4,123
4.2.5.	4,889
4.2.6.1.	2,550
4.2.6.2.	345
4.2.6.3.	218

	$53,160

6.1. & 6.2. Crushing Capital & Operating Cost

Mine production = 38,000 t/d
Retort feed (see Section 4.) = 38,000(1-.18) = 31,160 t/d
Alumina recovery feed (see Section 4.) = 31,160-0.95(4,770) = 26,628 t/d
Nahcolite recovery crushing factor = 0.104
Counter gravity crushing factor = 0.327
Alumina recovery crushing factor = 4.731

6.1. Capital Cost

C =
[4,339,727(.104)+3,828,184(.327-.104)+3,466,196(4,731-.327)]
[1.070(.62)+1.043(.07+.09)+1.171(.22)] =
16,570,144(1.0879) = $\$18,027\text{x}10^{3}$

6.2. Operating Cost

CL = 1,852(1.007) = $1,995
CS = [1,938(.104)+1,619(.327-.104)+1,404(4.731-.327)](1.000) = $6,746
CE = [2,167(.104)+1,796(.327-.104)+1,547(4.731-.327)](1.070) = 7,439(1.070) = $7,960
C = (1,995+6,746+7,960) = $16,701

7. Retorting and Auxiliary Processes

Shale oil content adjustment factor = .146/.153 = .954
Adjusted input value = .954(4,770) = 4,551 m^3/d

7.5. Counter Gravity Indirect Heated Steam Gas Recovery

7.5.1. Capital Cost

$C = 63,369,126(1.061) = \$67,235\text{x}10^{3}$

7.5.2. Operating Cost

$C = (18,574+9,134+3,430)(1.092) = \$34,003$

7.6. Nahcolite Recovery

7.6.1. Capital Cost

$C = 37,913,928(.1061) = \$40,227\text{x}10^{3}$

7.6.2. Operating Cost

$C = (3,003+6,402+5,416)(1.092) = \$16,185$

7.7. Alumina Recovery

7.7.1. Capital Cost

$C = 57,435,033(1.061) = \$60,939\text{x}10^{3}$

7.7.2. Operating Cost

$C = (9,453+60,966+4,133)(1.092) = \$81,411$

Total Capital Cost Group 7.

7.5.1.	$\$\ 67,235\text{x}10^{3}$
7.6.1.	$40,227\text{x}10^{3}$
7.7.1.	$60,939\text{x}10^{3}$
	$\$168,401\text{x}10^{3}$

Total Operating Cost Group 7.

7.5.2.	\$ 34,003
7.6.2.	16,185
7.7.2.	81,411
	\$131,599

9.1. Upgrading Capital Cost

9.1.1. Composite Plant
C = 72,408,012 = \$76,824,901
9.1.6. Delayed Coking
Cost based on actual feed at 1,270 m^3/d and Table 9. slate at 1,050 m^3/d.
C = (15,662,107-14,492,506)(1.061) = \$1,240,947
Adjusted Composite Plant
(76,824,901+1,240,947) = \$78,065,848 = \$78,066x10^3
9.1.10. Upgrading Support Equipment
9.1.10.1. Water Treatment
C = 3,163,217(1.061) = \$3,356x10^3
9.1.10.2. Cooling Towers
C = 760,053(1.061) = \$806x10^3
9.1.10.3. Steam Production
C = 3,470,207(1.061) = \$3,682x10^3
9.1.10.4. Compressed Air
C = 331,221(1.061) = \$351x10^3

Total Capital Cost Group 9.1.

9.1.1. & 9.1.6.	\$78,066x10^3
9.1.10.1.	3,356x10^3
9.1.10.2.	806x10^3
9.1.10.3.	3,682x10^3
9.1.10.4.	351x10^3
	\$86,261x10^3

9.2. Upgrading Operating Cost

9.2.1. Operating Cost
Adjustment factor = 78,065,848/76,824,901 = 1.016
C = [25,570+17,136(1.016)+5,423(1.016)(1.092) = \$52,951

10. Facilities For Retorting, and Upgrading

10.1 Facilities For Retorting and Upgrading Capital Cost

10.1.1. Site Development

$C = 260{,}726(1.061) = \$277\text{x}10^{3}$

10.1.2. Drainage & Sewers

$C = 613{,}293(1.061) = \$651\text{x}10^{3}$

10.1.3.1. Electrical Distribution

$C = 10{,}988{,}982(1.061) = \$11{,}659\text{x}10^{3}$

10.1.3.2. Water Supply

$C = 4{,}104{,}302(1.061) = \$4{,}355\text{x}10^{3}$

10.1.3.3. Communications System

$C = 181{,}555(1.061) = \$193\text{x}10^{3}$

10.1.3.4. Utility Support

$C = 1{,}409{,}514(1.061) = \$1{,}495\text{x}10^{3}$

10.1.3.5. Alarms & Instrumentation

$C = 1{,}091{,}660(1.061) = \$1{,}158\text{x}10^{3}$

10.1.4. Paving & Yardwork

$C = 438{,}136(1.061) = \$465\text{x}10^{3}$

10.1.5. Buildings

$C = 3{,}258{,}970(1.061) = \$3{,}458\text{x}10^{3}$

10.1.6. Plant Security

$C = 230{,}091(1.061) = \$244\text{x}10^{3}$

10.1.7. Fire Protection

$C = 705{,}256(1.061) = \$748\text{x}10^{3}$

10.1.8. Tanks

$C = 7{,}754{,}359(1.061) = \$8{,}227\text{x}10^{3}$

10.1.9. Site Restoration

$C = 1{,}870{,}939(1.061) = \$1{,}985\text{x}10^{3}$

10.1.10. Administrative Equipment

$C = 81{,}996(1.061) = \$87\text{x}10^{3}$

Total Capital Cost Group 10.1.

10.1.1.	\$ 277x10^3
10.1.2.	651x10^3
10.1.3.1.	11,659x10^3
10.1.3.2.	4,355x10^3
10.1.3.3.	193x10^3
10.1.3.4.	1,495x10^3
10.1.3.5.	1,158x10^3
10.1.4.	465x10^3
10.1.5.	3,458x10^3
10.1.6.	244x10^3
10.1.7.	748x10^3
10.1.8.	8,227x10^3
10.1.9.	1,985x10^3
10.1.10.	87x10^3
	\$35,002x10^3

10.2. Facilities For Retorting & Upgrading Operating Cost

10.2.1.1. Administrative Salaries

$C = 1{,}724(1.092) = \$1{,}883$

10.2.1.2. Administrative Expenses

$C = 293(1.092) = \$320$

10.2.1.3. Administrative Equipment Operation

$C = 171(1.092) = \$187$

10.2.2. Facilities Operating Cost

$C = (2{,}629+182+656)(1.092) = \$3{,}786$

Total Operating Cost

10.2.1.1.	\$1,883
10.2.1.2.	320
10.2.1.3.	187
10.2.2.	3,786

	\$6,176

11. Spent Shale Disposal

Spent shale = 26,628-{.256(.11)[38,000-.25(5,472)]} =
26,628-1,032 = 25,596 t/d

11.2. Underground Disposal

11.2.1. Capital Cost

11.2.1.1. Pumps and Piping

Horizontal adjustment = [(1,100-1,500)/100](.03)+1 = 0.880
Vertical adjustment = [(400-300)/100](.04)+1 = 1.040
C =
1,105,075(0.880)(1.040)[1.070(.86)+1.043(.10)+1,171(.04)] =
$\$1{,}084\text{x}10^{3}$

11. Spent Shale Disposal

11.2.2. Operating Cost

11.2.2.1. Pumping Slurry

No vertical adjustment factor required

Horizontal adjustment = [(1,100-1,500)/100](.07)+1 = 0.720

CL = 260(1.077) = $280

CS = 131(.72)(1.000) = $94

CE = 33[1.070(.90)+1.115(.10)] = $35

C = (280+94+35) = $409

11.2.2.2. Panel Preparation

CL = 2,105(1.077) = $2,267

CS = 888(1.171) = $1,040

CE = 195[1.092(.15)+1.115(.43)+1.070(.42)] = $213

C = (2,267+1,040+213) = $3,520

11.2.2.3. Pumping Decant Water

Horizontal adjustment factor = [(1,100-1,500)/500](.01)+1 = .992

Vertical adjustment factor = [(400-300)/100](0.30)+1 = 1.300

CL = 436(1.077) = $470

CS = 281(.992)(1.3)(1.000) = $362

CE = 148[1.070(.90)+1.115(.10)] = $159

C = (470+362+159) = $991

Total Operating Cost Group 11.2.

11.2.2.1.	$ 409
11.2.2.2.	3,520
11.2.2.3.	991

	$4,920

12. Transportation

From Table 9. syncrude quantity to be transported = 5,132 m^3/d

12.1. Transportation Capital Cost

12.1.1. Pipeline from Plant to Loading Facilities

$C = (3,380,000+28,238)(30/26)(1.171) = \$4605x10^3$

12.1.2. Rail Loading Facilities

$C = 1,232,148(1.171) = \$1,443x10^3$

12.1.3. Rail Transportation Equipment

No. of strings = 5,132/1,590 = 3.228

Factor = 4.248

$C = 990,000(3,228)(4.248)(1.074) = \$14,580x10^3$

Total Capital Cost Group 12.1.

12.1.1.	$\$4,605x10^3$	4,188,000
12.1.2.	$1,443x10^3$	
12.1.3.	$14,580x10^3$	

	$\$20,628x10^3$	

12.2. Transportation Operating Cost

12.2.1. Pipeline from Plant to Loading Facilities

CL = 515(.64)(1.077)+352(1.077) = $734
CS = 515(.14)(1.068)+48[1.000(.90)+1.068(.1)] = $125
CE =
515(.22)[1.115(.66)+1.070(.34)]+18[1.115(.10)+1.070(.90)] =
$144
C = (734+125+144)(30/26) = $1,157

12.2.2. Rail Loading Facilities

CL = 842(1.077) = $907
CS = 32[1.000(.42)+1.068(.58)] = $33
CE = 84[1.115(.66)+1.070(.34)] = $92
C = (907+33+92) = $1,032

12.2.3. Rail Transportation

C = 5.83(3,000)(3.228)(1.074) = $60,636

Total Operating Cost Group 12.2.

12.2.1.	$ 1,157
12.2.2.	1,032
12.2.3.	60,636
	$62,825

Summary of Capital and Operating Cost with Underground Mine

Section No.	Capital Cost	Operating Cost/Day
3.	$\$\ 1,361\mathrm{x}10^{3}$	-
Subtotal	$\$\ 1,361\mathrm{x}10^{3}$	
4.	$\$\ 26,452\mathrm{x}10^{3}$	$ 53,160
12.	$20,628\mathrm{x}10^{3}$	62,825
Subtotal	$\$\ 47,080\mathrm{x}10^{3}$	
13.1.1. Engr. Fee	$\$\ 2,150\mathrm{x}10^{3}$	-
13.1.1. CM Fee	$1,597\mathrm{x}10^{3}$	-
Subtotal	$\$\ 3,747\mathrm{x}10^{3}$	
6.	$\$\ 18,027\mathrm{x}10^{3}$	$ 16,701
7.	$168,401\mathrm{x}10^{3}$	131,599
9.	$86,261\mathrm{x}10^{3}$	52,951
10.	$35,002\mathrm{x}10^{3}$	6,176
11.	$1,084\mathrm{x}10^{3}$	4,920
Subtotal	$\$308,775\mathrm{x}10^{3}$	$328,332
13.1.1. Engr. Fee	$\$\ 14,030\mathrm{x}10^{3}$	-
13.1.1. CM Fee	$10,056\mathrm{x}10^{3}$	-
13.1.2. Working Capital	$21,670\mathrm{x}10^{3}$	-
Subtotal	$\$\ 45,756\mathrm{x}10^{3}$	
TOTAL	$\$406,719\mathrm{x}10^{3}$	$328,332

5.1. Open Pit Mine Capital Cost

5.1.1. Preproduction Development

Based on 30 m of overburden with surface diameter of 510 m and base diameter of 330 m.
Surface area = $Pi(255)^{2}x10^{-4}$ = 20 ha
Base area = $Pi(165)^{2}x10^{-4}$ = 9 ha
Topsoil removal = $20x10^{4}(.2)$ =
40,000 m^{3} at 2,000 m^{3}/d on one shift operation.
Overburden tonnage = $2.6(20+9)x10^{4}(.5)(30)$ = 11,310,000 t
Based on a one year, seven day week,
3 shift subcontracted operation at 32,000 t/d.
Use a pit depth of 30 m and a haul distance of
2,000 m for overburden.
Use 500 m topsoil haul distance on level grade.
Stripping ratio is 10(2.07):3(2.6) = 1:0.377, therefore total tons per day of oil shale and overburden is 38,000+.337(38,000) =
38,000+14,326 = 38,000+14,300 = 52,300 t/d

5.1.1.1. Preproduction Clearing
CL = 14,873(1.043)(1.50) = \$23,269
CS = 2,053[1.115(.57)+1.068(.43)](1.20) = \$2,697
CE = 4,942[1.070(.60)+1.115(.39)+1.092(.01)](1.50)(1.20) =
\$9,676
C = (23,269+2,697+9,676) = $\$36x10^{3}$

5.1.1.2. Preproduction Topsoil Removal
Labor F = $.0501(500)^{.440}(1)^{1.530}$ = 0.772
Equipment F = $.0274(500)^{.529}(1)^{1.620}$ = 0.734
CL = .585(40,000)(1.043)(1.50)(.772) = \$28,262
CE = .457(40,000)[1.070(.48)+1.115(.28)+1.092(.24)]
(2.05)(1.20)(.734) = \$35,908
C = (28,262+35,908) = $\$64x10^{3}$

5.1.1.3. Preproduction Drill and Blast - Overburden
CL = .0270(11,310,000)(1.043)(1.50) = \$477,751
CS = .0747(11,310,000)[1.048(.10)+1.068(.90)](1.20) =
\$1,080,741
CE = .00933(11,310,000)[1.070(.44)+1.115(.54)+1.092(.02)]
(2.47)(1.20) = \$342,400
C = (477,751+1,080,741+342,400) = $\$1,901x10^{3}$

5.1.1.4. Preproduction Load and Haul-Overburden
Labor F = $.0967(30)^{.030}(2,000)^{.263}$ = 0.791
Equipment F = $.0422(30)^{.047}(2,000)^{.353}$ = 0.724
CL = .191(11,310,000)(1.043)(1.50)(.791) = \$2,673,302
CS = .025(11,310,000)(1.000)(1.20) = \$339,300
CE = .266(11,310,000)[1.070(.24)+1.115(.36)+1.092(.40)]
(2.03)(1.20)(.724) = \$5,809,974
C = (2,673,302+339,300+5,809,974) = $\$8,823x10^{3}$

5.1.2. Mine Facilities

5.1.2.1. Drainage System
C = 482,626[1.043(.27)+1.070(.40)+1.171(.33)] = $\$529x10^{3}$

5.1.2.2. Communications System
C = 53,522[1.043(.20)+1.070(.80)] = $\$57x10^{3}$

5.1.2.3. Buildings
C = 2,250,023[1.043(.18)+1.171(.61)+1.070(.21)] = $\$2,535x10^{3}$

5.1.2.4. Electrical System

$C = 343{,}986[1.043(.20)+1.070(.80)] = \$366\text{x}10^{3}$

5.1.3. Mine Equipment

5.1.3.1. Excavation Equipment

Use a depth of 30 m with a haul of 2,500 m for overburden and a depth of 130 m with a haul of 3,000 m for oil shale.

Overburden $F = .0422(30)^{.047}(2{,}500)^{.353} = .784$

Oil shale $F = .0359(130)^{.047}(3{,}000)^{.353} = .762$

$C = 4{,}953{,}944(1.070)(.784)+12.648{,}442(1.070)(.762) = 4{,}155{,}765+10{,}312{,}781 = \$14{,}469\text{x}10^{3}$

5.1.3.3. Administrative Equipment

$C = 126{,}040(1.070) = \$135\text{x}10^{3}$

Total Capital Cost Group 5.1.

5.1.1.1.	$\$ 36\text{x}10^{3}$
5.1.1.2.	$64\text{x}10^{3}$
5.1.1.3.	$1{,}901\text{x}10^{3}$
5.1.1.4.	$8{,}823\text{x}10^{3}$
5.1.2.1.	$529\text{x}10^{3}$
5.1.2.2.	$57\text{x}10^{3}$
5.1.2.3.	$2{,}535\text{x}10^{3}$
5.1.2.4.	$366\text{x}10^{3}$
5.1.3.1.	$14{,}469\text{x}10^{3}$
5.1.3.3.	$135\text{x}10^{3}$
	$\$28{,}915\text{x}10^{3}$

5.2. Open Pit Mine Operating Cost

5.2.1. Production Development

Stripping ratio is 10(2,07):3(2.6) = 1:0.377, therefore at 38,000 t/d of oil shale production overburden = 38,000(.377) = 14,326 t/d. Use 14,300 t/d.

5.2.1.1. Clearing

Using the same clearing rate as used for preproduction clearing

Clearing rate = $.196(20)^{.645}$ = 1.353 ha/d
Area to be cleared at 38,000 t/d production =
38,000/[100(2.07)] = 184 m^2/d = .0184 ha/d
Adjustment factor = .0184/1.353 = .0136
CL = 1008(.0136)(1.077) = $15
CS = 139(.0136)[1.115(.57)+1.048(.43)] = $2
CE = 336(.0136)[1.070(.60)+1.115(.39)+1.092(.01)] = $5
C = (15+2+5) = $22

5.2.1.2. Topsoil Removal

Labor F = $.0501(500)^{.440}(1)^{1.530}$ = 0.772
Equipment F = $.0274(500)^{.529}(1)^{1.620}$ = 0.734
Using same daily area as clearing:
$1.353x10^4(.2)$ = 2,706 m^3/d
Adjustment factor from clearing rate = .0136
CL = 1,452(.0136)(.772)(1.070) = $16
CE = 1,183(.0136)(.734)[1.070(.48)+1.115(.28)+1.092(.24)] = $13
C = (16+13) = $29

5.2.1.3. Drill and Blast - Overburden

CL = 515(1.077) = $555
CS = 1,119(1.070) = $1,197
CE = 170[1.070(.44)+1.115(.54)+1.092(.02)] = $186
C = (555+1,119+170) = $1,844

5.2.1.4. Load and Haul - Overburden

Labor F = $.0967(30)^{.030}(2,000)^{.263}$ = .791
Equipment F = $.0422(30)^{.047}(2,000)^{.353}$ = .724
CL = 3,535(.791)(1.077) = $3,011
CE = 4,167(.724)[1.070(.24)+1.115(.36)+1.092(.40)] = $3,304
C = (3,011+3,304) = $6,315

5.2.2. Mining Oil Shale

5.2.2.1. Drill and Blast - Oil Shale

CL = 1,053(1.077) = $1,134
CS = 3,107[1.048(.10)+1.068(.90)] = $3,312
CE = 342[1.070(.44)+1.115(.54)+1.092(.02)] = $374
C = (1,134+3,312+374) = $4,820

5.2.2.2. Load and Haul - Oil Shale

Labor F = $.0862(130)^{.030}(3,000)^{.263}$ = .819
Equipment F = $.0359(130)^{.047}(3,000)^{.353}$ = .762
CL = 8,371(.819)(1.077) = $7,384
CS = 950(1.000) = $950
CE = 13,009(.762)[1.070(.22)+1.115(.36)+1.092(.42)] = $10,859 = $10,859
C = (7,384+950+10,859) = $19,193

5.2.3. General Expense

5.2.3.1. Administrative Salaries

C = 2,305(1.25)(1.077) = $3,103

5.2.3.2. Administrative Expenses

$C = 347(1.068) = \$371$

5.2.3.3. Administrative Equipment

$C = 166[1.092(.02)+1.115(.37)+1.077(.21)+1.070(.40)] = \$181$

Total Operating Cost Group 5.2.

5.2.1.1.	$ 22
5.2.1.2.	29
5.2.1.3.	1,844
5.2.1.4.	6,315
5.2.1.4.	4,820
5.2.2.2.	19,193
5.2.3.1.	3,103
5.2.3.2.	371
5.2.3.3.	181

	$35,878

Summary of Capital and Operating Cost with Open Pit Mine

Section No.	Capital Cost	Operating Cost/Day
3.	$\$\ 1,361x10^3$	-
Subtotal	$\$\ 1,361x10^3$	
5.	$\$\ 28,915x10^3$	$ 35,878
Subtotal	$\$\ 28,915x10^3$	
13.1.1. Engr. Fee	$\$\ 1,106x10^3$	-
13.1.1. CM Fee	$805x10^3$	-
Subtotal	$\$\ 1,911x10^3$	
12.	$\$\ 20,628x10^3$	$ 62,825
Subtotal	$\$\ 20,628x10^3$	
13.1.1. Engr. Fee	$\$\ 1,022x10^3$	-
13.1.1. CM Fee	$730x10^3$	-
Subtotal	$\$\ 1,752x10^3$	
6.	$\$\ 18,027x10^3$	$ 16,701
7.	$168,401x10^3$	131,599
9.	$86,261x10^3$	52,951
10.	$35,002x10^3$	6,176
11.	$1,084x10^3$	4,920
Subtotal	$\$308,775x10^3$	$311,050
13.1.1. Engr. Fee	$\$\ 14,030x10^3$	-
13.1.1. CM Fee	$10,056x10^3$	-
13.1.2. Working Capital	$20,529x10^3$	-
Subtotal	$\$\ 44,615x10^3$	
TOTAL	$\$407,957x10^3$	$311,050

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